CORPS OF ENGINEERS, U. S. ARMY

PLANS FOR IMPROVEMENT OF NAVIGATION CONDITIONS IN CORRAL BAY AND THE VALDIVIA RIVER, CHILE

HYDRAULIC MODEL INVESTIGATION

TECHNICAL MEMORANDUM NO. 2-382

CONDUCTED FOR

DEPARTMENT OF PORTS
GOVERNMENT OF CHILE

BY

WATERWAYS EXPERIMENT STATION
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PREFACE

This model study of the Valdivia River and Corral Bay was made for the Department of Ports, Government of Chile, by the Hydraulics Division of the Waterways Experiment Station, Corps of Engineers, Vicksburg, Mississippi, during the period 1950 to 1953. Arrangements for the study were made by the Chilean Ambassador to the United States with the Department of State, U. S. Government. Performance of the study by the Waterways Experiment Station was authorized by the Chief of Engineers, U. S. Army, on 23 October 1950.

CONTENTS

PLANS FOR IMPROVEMENT OF NAVIGATION CONDITIONS IN CORRAL BAY AND THE VALDIVIA RIVER, CHILE

Hydraulic Model Investigation

PART I: INTRODUCTION

1. This report presents the results of a comprehensive model investigation of plans for improvement of navigation conditions in Corral Bay and the Valdivia River, located in the southern portion of Chile. The port of Corral, located in Corral Bay, is the principal port in the southern portion of Chile, and the Valdivia River forms a navigable waterway connecting the port of Corral with Valdivia, the largest city in this portion of Chile.

2. The report contains descriptions of the prototype and of the model; a discussion of the adjustment and verification of the model; the results of all model tests of proposed improvement plans; and the conclusions reached after analysis of the results of all model tests. A plan of improvement is recommended for construction in the prototype; this plan is considered to provide the best and most economical solution of the problems involved of all the plans tested.

PART II: THE PROTOTYPE

Location and Description of Problem Area

3. The Valdivia River and Corral Bay form a natural waterway from the city of Valdivia, Chile, to the Pacific Ocean, as shown on the vicinity map, fig. 1, and the location map, fig. 2. The river channel from the city of Valdivia to its mouth in Corral Bay has been improved in past years by construction of a comprehensive system of longitudinal training walls, with the result that depths throughout this reach of the river are adequate for navigation (controlling depths of six meters or more at MLLW*). In Corral Bay, however, between the mouth of the Valdivia River and the port of Corral, natural depths are of the order of three to four meters and are not sufficient to permit oceangoing vessels to cross the bay and enter the improved river channel.

4. The port of Corral is located on the west side of Corral Bay and is one of the most important ports in Chile, being the only deep-water port in the southern portion of the country. Because of the shallow natural depth of Corral Bay between the port of Corral and the mouth of the Valdivia River, all freight traffic between the port of Corral and the city of Valdivia must be handled by lighters, or very shallow-draft vessels. As an example of the high cost involved in handling freight shipments in this manner, representatives of the Chilean Government have stated that the cost of lightering a ton of freight from the city of Valdivia to the port of Corral and loading it on an oceangoing ship is greater than the cost of transporting a ton of freight from the port of Corral to London, England.

Problems Involved

5. The natural depths of the access channel and anchorage areas of the port of Corral are adequate for navigation, but the width of the

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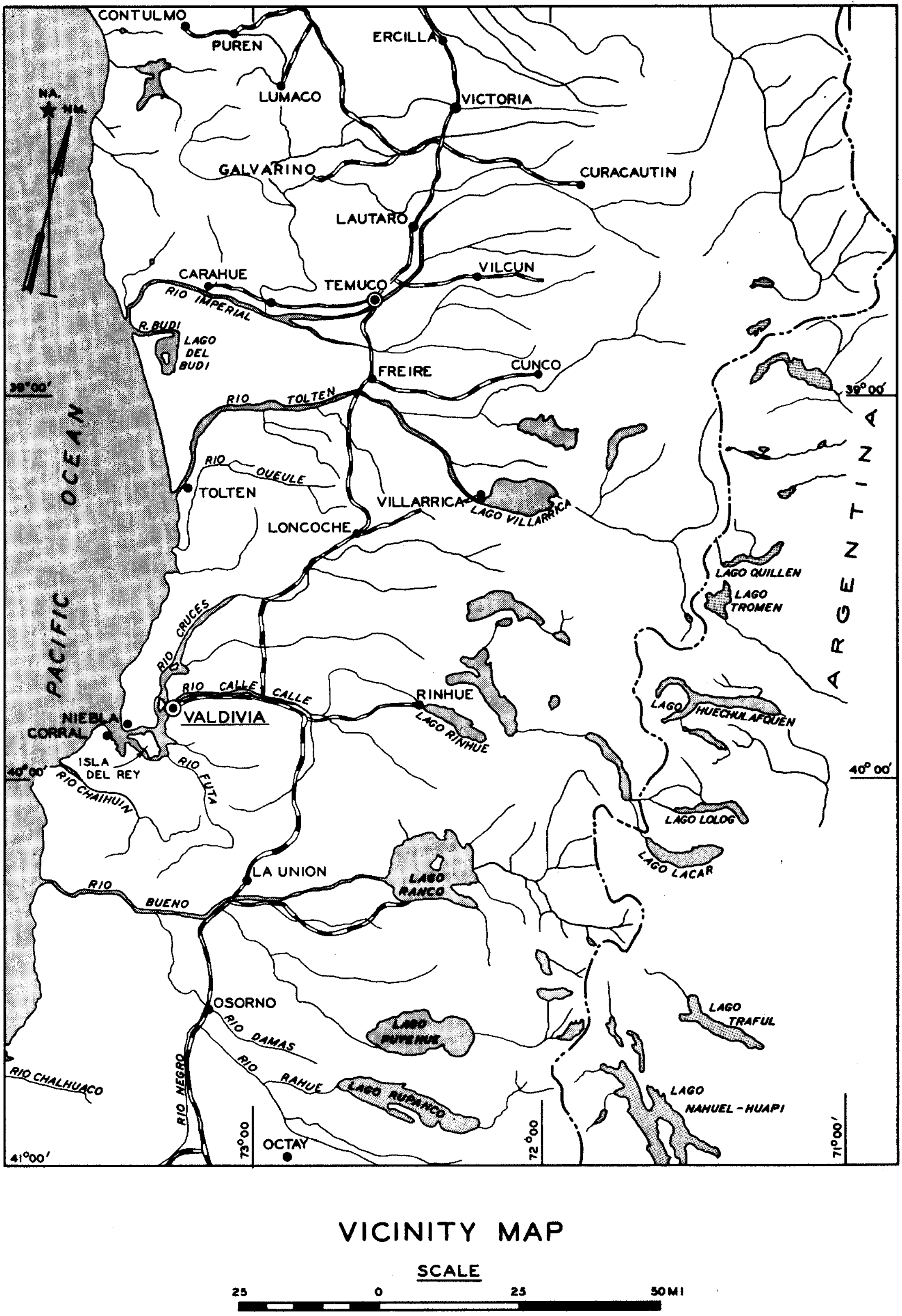
* Mean lower low water.



VICINITY MAP

FIGURE 1

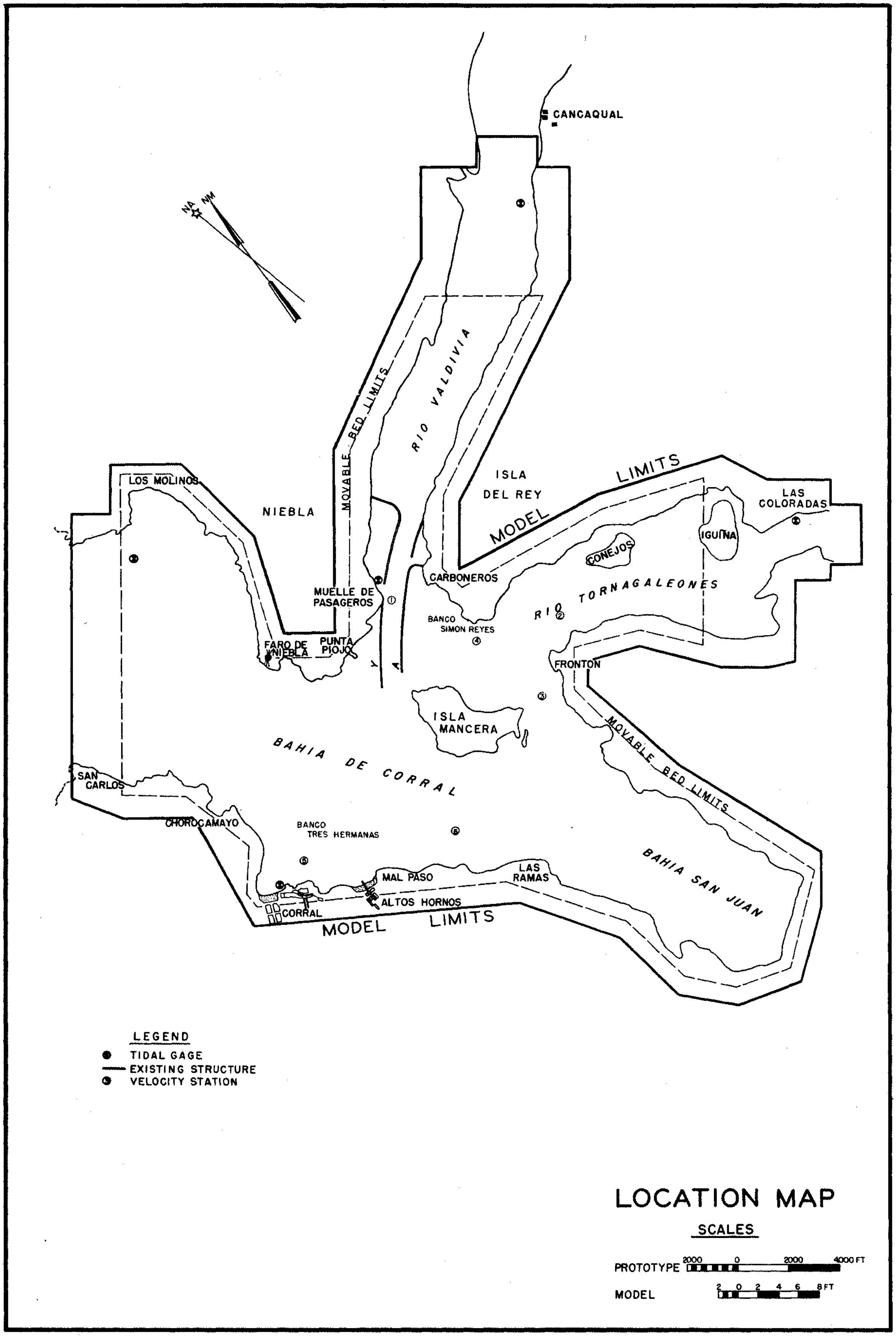

CANCAQUAL
NA
NM
RIO VALDIVIA
MOVABLE BED LIMITS
ISLA
DEL REY
MODEL LIMITS
LAS
COLORADAS
IGUIÑA
CONEJOS
LOS MOLINOS
NIEBLA
MUELLE DE
PASAGEROS
CARBONEROS
RIO TORNAGALEONES
BANCO
SIMON REYES
FARO DE
NIEBLA
PUNTA
PIOJO
FRONTON
ISLA
MANCERA
BAHIA DE CORRAL
SAN
CARLOS
CHOROCAMAYO
BANCO
TRES HERMANAS
MAL PASO
LAS
RAMAS
ALTOS HORNOS
CORRAL
MODEL LIMITS
MOVABLE BED LIMITS
BAHIA SAN JUAN
LEGEND
TIDAL GAGE
EXISTING STRUCTURE
VELOCITY STATION
LOCATION MAP
SCALES
PROTOTYPE 2000 0 2000 4000 FT
MODEL 2 0 2 4 6 8 FT

FIGURE 2

deep-water portion of the port is being progressively decreased by a westerly movement of Three Sisters Shoal (Banco Tres Hermanas), which is located just east of the port (fig. 2). Some consideration has been given to dredging along the west side of Three Sisters Shoal to increase the width of the deep-water portion of the anchorage area; however, the benefit that might be derived from such dredging is very doubtful as long as natural forces supply material to the shoal at the present rate. It is therefore desirable that a plan of improvement be developed to permit enlargement of the anchorage area at the port of Corral, either through natural scour by the tidal currents or by dredging in conjunction with some structure that would greatly reduce the present supply of material to Three Sisters Shoal and thus assure that the additional width gained by dredging would not be lost within a short time.

6. A channel across Corral Bay having a controlling depth of about six meters at MLLW would greatly reduce the tonnage of freight now handled by lighters, since most of the ships that now load and unload at the port of Corral could then navigate the river channel to and from the city of Valdivia. Therefore, an over-all plan of improvement should include provisions for obtaining and maintaining a channel of at least six meters depth at MLLW from deep water in Corral Bay to the Valdivia River entrance, upstream from which existing channel depths to the city of Valdivia are adequate for navigation.

7. Wave action in Corral Bay is sufficiently severe under certain storm conditions to constitute a hazard to small craft and reduce the efficiency of loading and unloading operations at the port of Corral. Although the problem of wave action is of much less magnitude than the problems described in the preceding two paragraphs, it would be desirable that the over-all improvement plans afford protection to the port of Corral from storm waves.

Causes of the Problems

8. The shallow natural depths between the mouth of the Valdivia River and the port of Corral, and the progressive westerly encroachment

of Three Sisters Shoal toward the port, indicate that sediments are being supplied to the central portion of the bay faster than the tidal currents can remove them. Available evidence indicates that the sediment supply to the problem area is derived partially from riverborne detritus and partially from littoral transport.

9. The drainage area of the Valdivia River is principally mountainous and is subject to heavy rains with resultant quick runoff; therefore, the river carries an appreciable sediment load, especially during the rainy season. Between the city of Valdivia and Corral Bay, the river channel is fairly stable as a result of the system of longitudinal training walls constructed throughout that reach; therefore, very little, if any, of the sediment load of the river is dropped in the improved reach. However, when the sediment-laden water reaches Corral Bay, the sediment load is probably deposited over a large fan-shaped area of the bay as dictated by the velocities of the tidal currents and the action of waves.

10. The normal direction of littoral drift along the southern coast of Chile is from north to south. It appears likely that tidal current action in Corral Bay intercepts some portion of the coastal drift, and that material thus intercepted moves in a southerly direction along the east side of Corral Bay to the central portion of the bay. The fact that the angle between jetty Y (fig. 2) and the shore was rapidly filled with sediment soon after the jetty was constructed in 1944 is evidence of a southerly drift of material along the east side of the central portion of Corral Bay.

11. Available information indicates that the central portion of Corral Bay, and especially Three Sisters Shoal, is the focal point for movement of sediment derived both from the Valdivia River and the southerly littoral drift along the east side of Corral Bay. It is probable that the rate at which material is supplied to the problem area from either of these sources is quite variable, since the maximum rate of supply from the river is probably related to the flood season, and the maximum rate from the littoral drift is probably related to certain severe storm conditions. However, the normal action of the tidal currents and waves in Corral Bay probably sorts and arranges the material

in such manner that trends of change are more or less constant with time, and the effects of seasonal changes in rates of supply are obliterated.

PART III: THE MODEL

Description

Area reproduced

12. The Valdivia River model was a scale reproduction of that portion of Corral Bay extending upstream from a line drawn from Los Molinos to Point San Carlos to and including San Juan Bay. The model also included the Tornagaleones River from its mouth to Las Coloradas, and the Valdivia River from its mouth in Corral Bay to the mouth of the Cutipay River (see fig. 2 for general layout of model).

Model scales

13. The model was constructed to linear scale relationships, model to prototype, of 1:400 horizontally and 1:80 vertically with a resultant slope scale of 5:1. Other scale relationships, computed from the linear scales, were: time, 1:44.72; velocity, 1:8.95; discharge, 1:286,200; and volume, 1:12,800,000. It is pointed out that the computed time scale of 1:44.72 was applied only to reproduction of prototype hydraulic forces in the model, and had no relation to the time required for the model to reproduce observed changes in prototype hydrographic conditions. The time scale for this latter relationship was determined empirically during the model bed-movement verification and is explained in detail in paragraphs 29 and 38.

Type of model

14. The model was of the movable-bed type in that the model bed was molded of erodible material throughout the critical area under study. An analysis of the forces available to move sediment in the prototype, in relation to the linear scales contemplated for the model, indicated that the model bed should be molded of crushed coal. This material was of proper weight to permit its movement by the model hydraulic forces in a manner similar to the movement of the prototype bed material by the prototype hydraulic forces. Consequently, the movable-bed portion of the model, outlined by dashed line on fig. 2, was molded of crushed coal having a specific gravity of 1.41, a grain-size range of 0.075 mm to

2.000 mm, and a median grain diameter of 0.800 mm.

15. The remainder of the model bed, beyond the limits of the movable-bed section shown in fig. 2, was molded of concrete to provide space for the wave generator and the inflow-outflow system required for each of the three tide reproducers. Traps were constructed just beyond the limits of the movable-bed section in Corral Bay, in the Tornagaleones River, and in the Valdivia River to prevent bed material from passing beyond the limits of the movable-bed section and into the water supply and return system. All bank slopes above MLLW were molded of concrete, because the crushed coal could not be molded to the steep slopes involved without sloughing extensively. General views of two portions of the model are shown in figs. 3 and 4.

Model Appurtenances

Tide generators

16. The master tide generator, located at the Corral Bay extremity

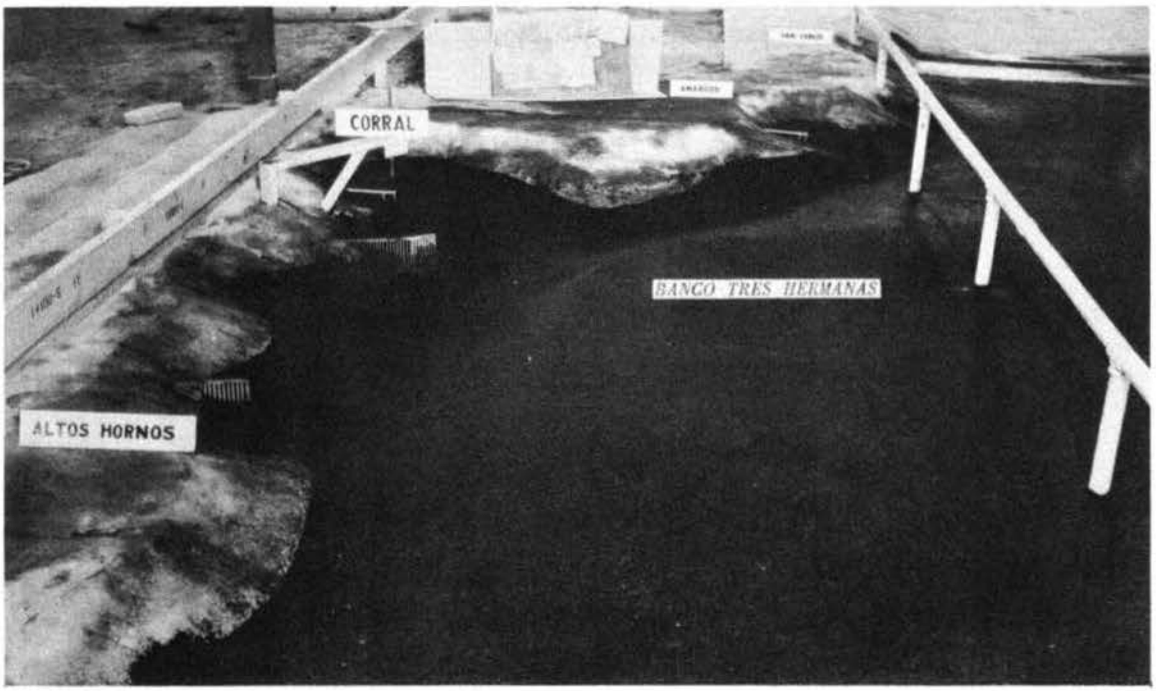


Fig. 3. General view of model looking northwest from San Juan Bay toward port of Corral. Note Three Sisters Shoal in top center

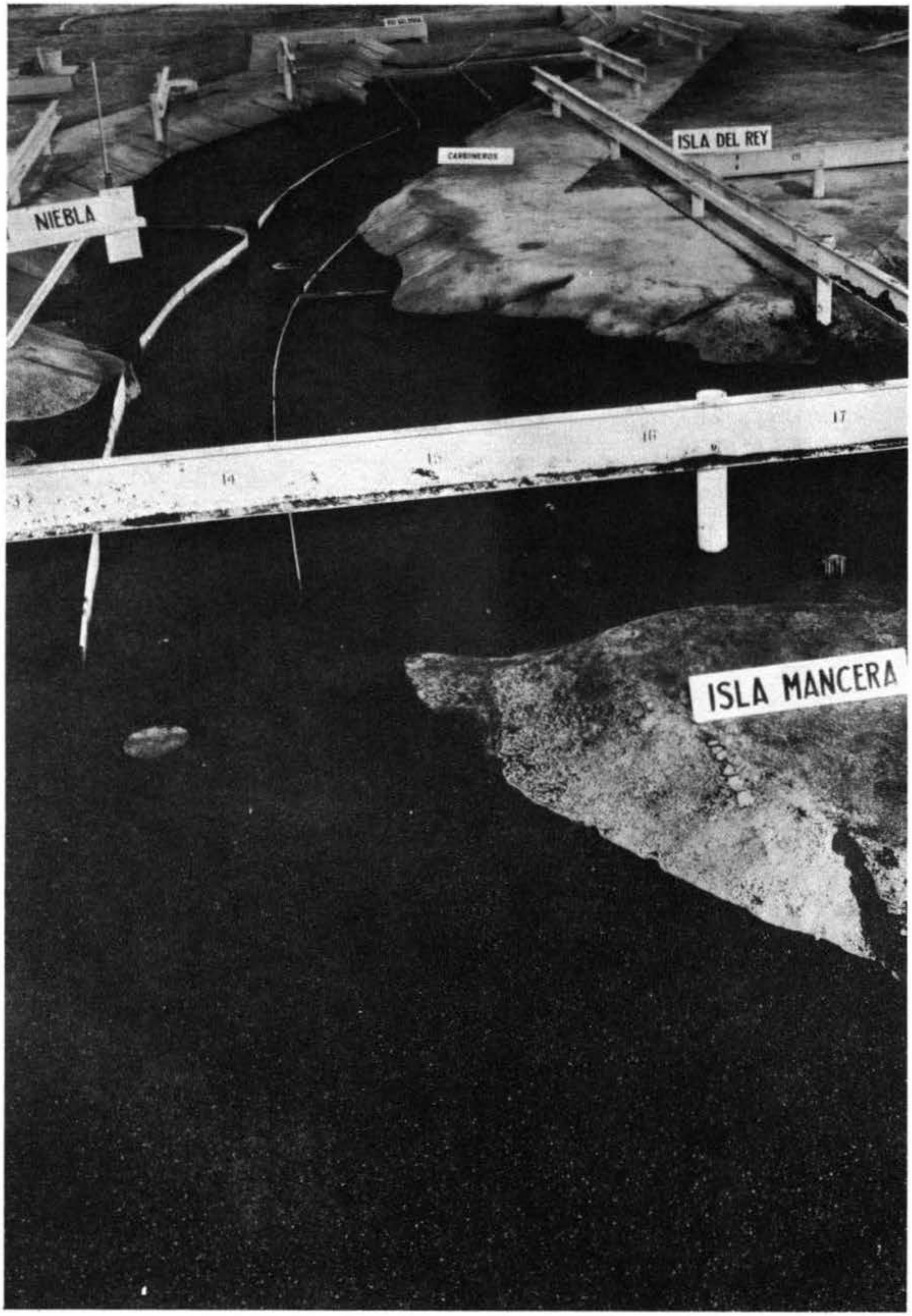


Fig. 4. General view of model looking upstream in Valdivia River from Mal Paso. Note templet and sounding rails

of the model, reproduced to scale the prototype mean tide at Los Molinos by maintaining at all times the proper balance between a pumped inflow of water to the model and a gravity outflow from the model as required to simulate all characteristics of the prototype tide being reproduced. The secondary tide generators, located at the extremities of the Tornagaleones and Valdivia Rivers, were adjusted to reproduce accurately the flood and ebb tidal discharges at the locations of the tide generators. With the three tide generators operating in unison, tidal elevations, tidal phases, and tidal discharges and velocities were reproduced accurately throughout the entire model. The master tide generator is shown in fig. 5.

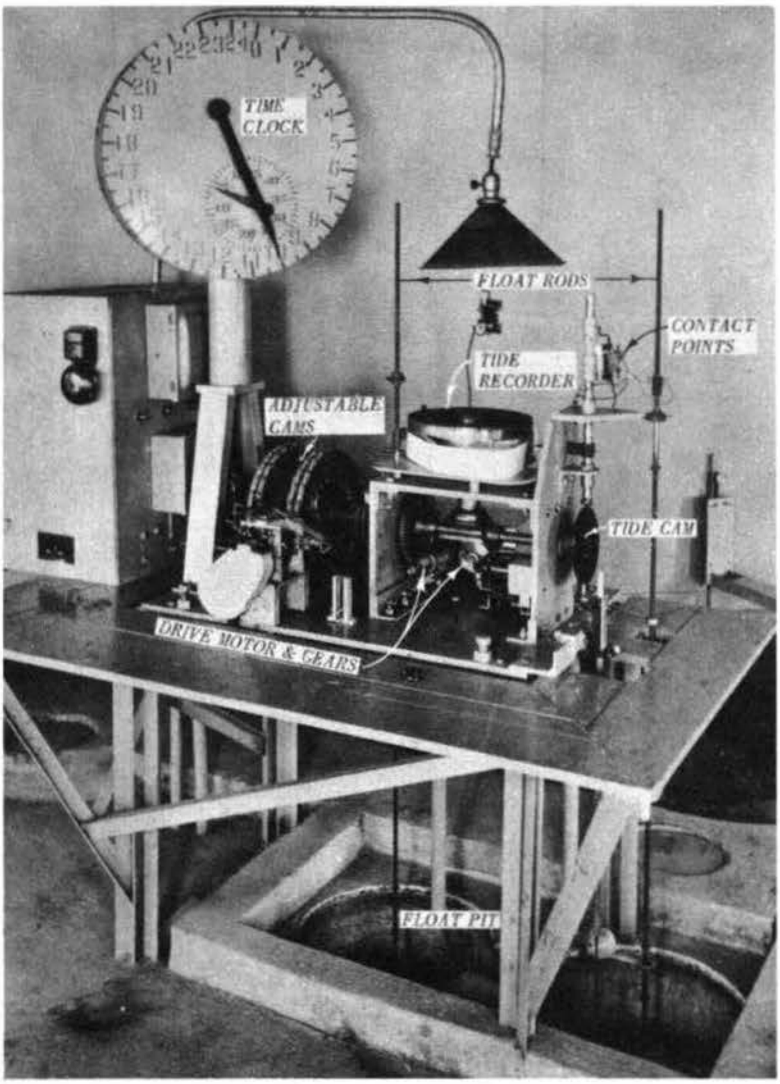


Fig. 5. Master tide generator

Wave generator

17. Prototype wave action was reproduced in the model by means of a 40-ft-long wave generator located at the Corral Bay extremity of the model. The wave generator was of the plunger type (see fig. 6), and could be quickly adjusted to produce the desired wave height, wave length, and wave period so that the model waves would move the model bed material in the same manner as prototype waves produce movement of bed material in the prototype.

Templets

18. At the beginning of each model test, the movable-bed section of the model was molded to conform to the prototype hydrographic survey used as the beginning of the verification period (discussed in part IV). To facilitate molding of the movable bed, a pattern of sounding ranges was established on the survey sheet, depths were determined in detail along each sounding range, and a plot of the bottom profile along each range was transferred to sheet-metal templets. These templets were suspended from graded rails as shown in fig. 7, so that molding of the

Fig. 6. General view of wave generator in operation

Fig. 7. View of bed molding operation using sheet-metal templets suspended from graded rails

movable bed to the prototype hydrographic survey could be accomplished quickly and accurately.

Sounding apparatus

19. The movable-bed section of the model was sounded, or surveyed, at the beginning and end of each test and at frequent intervals throughout the tests. The sounding apparatus, shown in fig. 8, page 14, consisted of a horizontally-graduated sounding board, mounted on the graded templet rails, and a vertically-graduated sounding rod to determine depths throughout the model. The graded templet rails constituted a horizontal control system for location of sounding ranges, as well as a vertical reference plane so that soundings could be referenced to MLLW. The sounding rod was so graduated that depths could be determined to the nearest foot (prototype), and the bottom of the sounding rod was equipped with a hinged metal shoe to prevent penetration of the rod into the coal bed of

the model. The movable-bed portion of the model could be completely surveyed with this apparatus in about six hours.

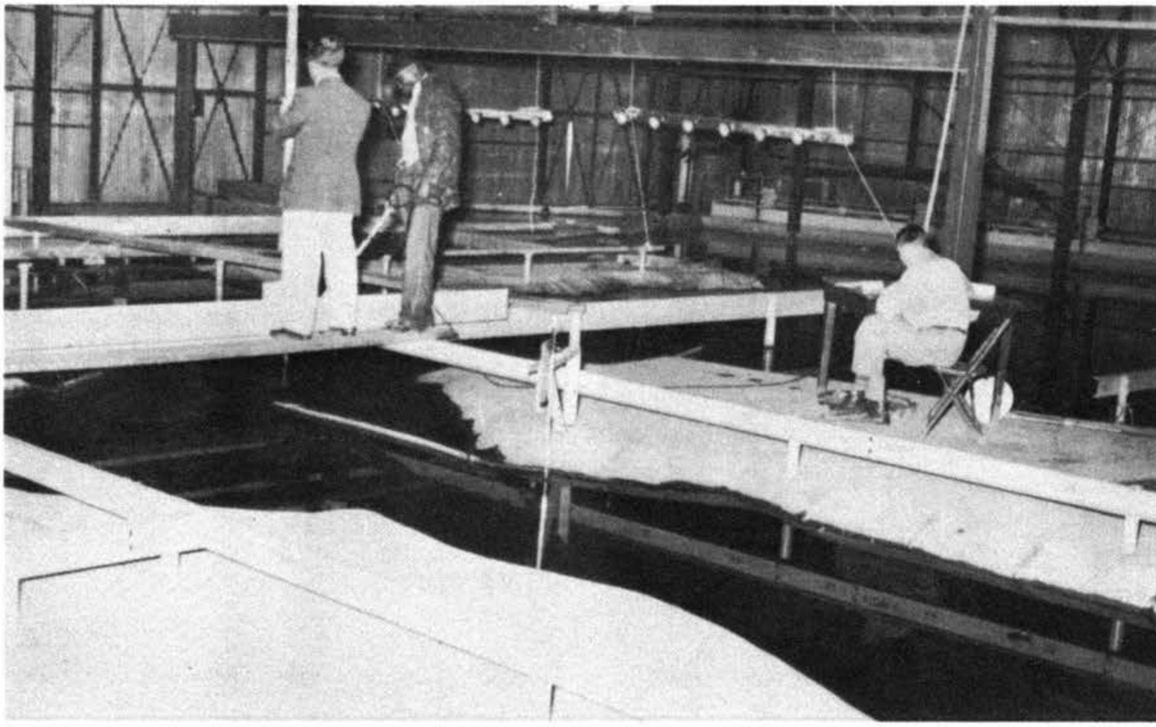


Fig. 8. View of sounding operation making use of horizontally-graduated sounding board mounted on graded rails and vertically-graduated sounding rod

PART IV: VERIFICATION OF THE MODEL

General Procedure

20. Verification of the Valdivia River model consisted of two seperate but interrelated phases as follows: (a) hydraulic verification, which resulted in a proper reproduction of prototype tidal heights and times, and current velocities and directions throughout the entire model; and (b) verification of bed movement, which resulted in an accurate reproduction of observed trends of prototype bed movement, as illustrated by a comparison of successive hydrographic surveys of the problem area, and which also permitted the model time scale for bed movement to be determined empirically.

Hydraulic Verification

Procedure

21. The initial step in the hydraulic verification consisted of adjusting the master tide generator to reproduce the observed 24.84-hour prototype tidal cycle of 28-29 January 1949 at the Los Molinos gage. This particular tide was selected for use in the model verification because the ranges were of approximately mean dimensions, and current velocities had been observed at middepth throughout the complete cycle at station 1 in the Valdivia River and station 2 in the Tornagaleones River (see fig. 2 for locations of tidal gages and velocity stations).

22. The fresh-water discharges of the Valdivia and Tornagaleones Rivers were extremely low (140 and 106 cu meters per sec, respectively) during the period 28 January-1 February 1949 when the prototype current velocity measurements that were used as a basis for adjustment of the secondary tide generators were made. It was desirable that proposed improvement plans be tested under conditions of mean fresh-water flows, which are 500 cu meters per sec for the Valdivia River and 375 cu meters per sec for the Tornagaleones River, instead of under the low discharges of 140 and 106 cu meters per sec. Therefore, the observed prototype

velocity measurements for both rivers were adjusted to mean fresh-water discharge conditions, and the secondary tide generators were adjusted to reproduce accurately the adjusted prototype current velocity measurements.

Results

23. The accuracy with which the model reproduced the observed prototype tides of 28-29 January 1949 at Los Molinos is shown by plate 1. Prototype tides on the above dates were also observed in the Valdivia River at Cancaqual, and at a gaging station in the Tornagaleones River near Las Colorados, but both of those prototype gages were located short distances upstream from the model limits in the two rivers. However, tidal observations for verification conditions were made in the model at the extremities of both rivers, and are plotted against the above-described observed prototype tides on plate 1 for comparison.

24. Plate 2 illustrates the accuracy with which the model reproduced observed prototype middepth current velocities at those stations in the Valdivia and Tornagaleones Rivers for which prototype data were available. When it was found that model and prototype current velocities were in close agreement, model current directions throughout the problem area were observed by releasing floats of various lengths and charting their paths of movement at both ebb and flood currents. Prototype data were not available for comparison with model float observations; however, the Chilean Government Representative who was stationed at the Waterways Experiment Station throughout the model study, and who was very familiar with prototype hydraulic phenomena, expressed the opinion that the current pattern of the model was very similar to that of the prototype.

Discussion of results

25. The accuracy with which the model tides conformed to observed prototype tides at Los Molinos and to the adjusted prototype current velocities in the Valdivia River indicated a satisfactory model reproduction of observed prototype hydraulic phenomena. Comparison of model tide observations at the extremities of the Valdivia and Tornagaleones Rivers with prototype observations at gages located upstream from the model limits indicated close agreement of the model and prototype tides. With

respect to time, the prototype observations indicate a time lag of about 0.25 to 0.50 hour as compared to model observations; however, since the prototype gages were located farther upstream than the model gages in both rivers, a time lag of the magnitude observed was to be expected.

26. Based on the accuracy with which the model reproduced observed prototype tidal elevations and times, and current velocities and directions, it is the opinion of the Waterways Experiment Station that the hydraulic adjustment of the model was entirely satisfactory. The accuracy of the hydraulic verification thus assured that the model would provide dependable information as to the effects of proposed improvement works on hydraulic conditions throughout the problem area.

Verification of Bed Movement

Principle of movable-bed model verification

27. The validity of tests of proposed improvement plans in a movable-bed model is based on the following premise: if the model reproduction of the prototype forces known to affect movement and deposition of sediments (tides, tidal currents, waves, etc.) produces changes in model bed configurations similar to those that have been observed in the prototype under similar conditions, then the effects of a proposed improvement plan on both hydraulic conditions and the movement and deposition of sediments will be the same in both model and prototype.

28. Trends and magnitudes of prototype bed movement under existing conditions are determined primarily by means of a detailed comparison of two or more periodic prototype surveys of the area under study. The time between the earliest and latest surveys used in this comparison is known as the verification period. The movable-bed portion of the model is molded to conform to the prototype survey at the beginning of the verification period; the model is then operated, under conditions which existed in the prototype during the verification period, until model bed configurations throughout the problem area are in conformance with those shown by the prototype survey at the end of the period. Model bed

movement is then considered to be verified, or in proper adjustment, if changes in the model bed configurations during the verification period agree reasonably well with those which occurred in the prototype during the corresponding period.

29. One highly important purpose of the verification of a movable-bed model is the establishment of the time scale with respect to bed movement. The model-to-prototype time scale for bed movement cannot be computed from the linear scale relationships (as are the other scale ratios) owing to the fact that the interrelation of the various prototype forces affecting movement and deposition of sediments is too complicated for accurate definition, and consequently is much too intricate to permit establishment of mathematical scale relationships for each component of force. The model-to-prototype time scale for bed movement is therefore determined empirically during the model verification; that is, the actual time required for the model to reproduce certain changes known to have occurred in a given period of time in the prototype is used to determine the model time scale for bed movement.

Procedure for trial verification tests

30. The verification period initially selected for the Valdivia River model was the 3 years between the prototype surveys of 1948 and 1951. A careful study was made to determine the changes in prototype bed configurations that had occurred between these two surveys, and the major changes noted were as follows: (a) the west side of Three Sisters Shoal was shown to have advanced appreciably in a westerly direction toward the port of Corral; and (b) the deep-water portion of the port of Corral was shown to have deepened appreciably during the 3-year period. No significant changes were noted throughout the remainder of Corral Bay or in the lower reaches of the Valdivia River, indicating that prototype bed configurations throughout the problem area were very stable except in the two areas mentioned above.

31. A number of trial verification tests were made to determine how accurately the model would reproduce the changes noted between the prototype surveys of 1948 and 1951. It was found in every test that the model would duplicate accurately the westerly encroachment of Three

Sisters Shoal; however, the model showed no noticeable trend toward appreciable deepening of the deep-water portion of the port of Corral as had been indicated by the prototype surveys. Furthermore, in each of the trial verification tests in the model, appreciable deepening and extension of the area of scour adjacent to the ends of the existing jetties at the Valdivia River mouth were noted, while comparison of the prototype surveys indicated no change in bed conditions in that area during the 3-year verification period.

Reanalysis of prototype data

32. The 1948 and 1951 prototype surveys were then reanalyzed in detail, and it was found that the 1948 survey consisted of a composite of several partial surveys made in 1944, 1946, 1947, and 1948, and was actually more nearly representative of the prototype conditions that existed in 1946 than of those existing in 1948, which happened to be the year of the latest partial survey used in its preparation. Therefore, this survey is referred to hereinafter as the 1946 prototype survey. It was also found that the only portions of the problem area actually surveyed in 1951, as shown on the 1951 prototype survey, consisted of Three Sisters Shoal and the port of Corral. The soundings throughout the remainder of Corral Bay and the Valdivia River shown on this survey had been transferred thereto from the 1946 survey, which accounted for the apparent stability of bed configurations noted everywhere except in the two areas mentioned in paragraph 30. Since the limited areas actually surveyed in 1951 constituted only a very small portion of the problem area, it was decided that the 1951 survey could not be used as a basis for verifying bed movement in the model. Consequently, a request for a new and comprehensive survey was made to the Chilean Department of Ports in February 1952, and the new survey was made later in 1952.

33. The 1946 prototype survey is shown on plate 3, and the 1952 prototype survey, which was used as the end survey of the verification period, is shown on plate 4. Plate 5 shows the changes, both scour and fill, that occurred in the prototype between the surveys of 1946 and 1952. The principal changes in prototype bed configurations noted for this 6-year period were as follows: (a) there was a distinct westerly

shift of the west side of Three Sisters Shoal, both in the vicinity of the port of Corral and opposite Chorocamayo; (b) the area of scour between and adjacent to the ends of the existing Valdivia River jetties was enlarged and deepened considerably during the period; (c) there was an appreciable fill in the angle between the north jetty at the Valdivia River entrance and the shore in the vicinity of Punta Piojo; (d) several fairly extensive fill areas developed in the central portion of Corral Bay between Three Sisters Shoal and Faro de Niebla; and (e) some scour was noted in the deep-water portion of the port of Corral opposite the dock facilities.

Procedure for final verification

34. Operation of the model was undertaken with the movable bed molded to the 1946 prototype survey (see plate 6 for detailed bed survey) to determine whether or not the model would reproduce the changes in prototype bed configurations discussed above and, if so, the period of time required for the model to reproduce such changes. The movable bed was surveyed at frequent intervals to maintain a progressive check on changes in model bed configurations. At the end of 36 tidal cycles of 33.3 minutes each, bed configurations in the model were found to be very similar to those indicated on the 1952 prototype survey. The model survey at the end of 36 tidal cycles is shown on plate 7, and should be compared with the 1952 prototype survey shown on plate 4. A scour and fill map, plate 8, was prepared to show the changes in model bed configurations that occurred during the 36-cycle period. Comparison of this map with the prototype scour and fill map on plate 5 illustrates the accuracy with which the model reproduced changes in prototype bed configurations between the prototype surveys of 1946 and 1952.

Results

35. Comparison of plates 5 and 8 indicates that the model reproduced most of the significant changes in prototype bed configurations for the 6-year period. Enlargement and deepening of the scour area at the Valdivia River entrance, filling north of the north jetty, westerly extension of Three Sisters Shoal, and general filling between Three Sisters Shoal and Faro de Niebla were all reproduced satisfactorily in

the model. The only significant prototype change that the model failed to reproduce was the scour along the east side of the deep-water portion of the port of Corral opposite the dock facilities.

36. Comparison of the 1952 prototype survey (plate 4) with the model survey at the end of 36 tidal cycles (plate 7) discloses that the model bed configurations were in close agreement with those shown on the prototype survey. Both the prototype and model surveys indicate a channel having a controlling depth of about 4.0 meters at MLLW connecting the Valdivia River entrance with the port of Corral, and located on an alignment about SSW from the Valdivia River entrance. Both surveys indicate a tendency toward development of a second channel, on an alignment almost due west from the northern tip of Mancera Island; however, Three Sisters Shoal lies between this second channel and the deep-water section of the port of Corral. The orientation of the secondary channel suggests that sediment supplied to the problem area from the Valdivia River follows this route to Three Sisters Shoal.

Discussion of results

37. The bed movement during verification of a movable-bed model cannot be expected to duplicate exactly changes in prototype bed configurations during the selected verification period for numerous reasons. First, the trends of bed movement in the prototype are not constant with time, while the model verification procedure constitutes an attempt to reproduce such movement on an average basis. Second, in many instances certain observed changes in prototype bed configurations are the result of storms or other extreme conditions, which the model verification, necessarily based on average conditions, cannot be expected to reproduce. Therefore, the model bed-movement verification is an attempt to reproduce the gross changes that occurred in the prototype between the beginning and end of the verification period, and minor discrepancies of a local nature or which are attributable to unusual prototype conditions, may be neglected from consideration. For example, the scour indicated by comparisons of the prototype surveys to have occurred along the east side of the deep-water portion of the port of Corral, and which the model failed to duplicate, probably occurred during times of extremely

large floods on the Valdivia River. Since the effects of such floods were not considered during the model verification, it could not be expected that the scour which they produced could be duplicated in the model.

38. The accuracy with which the model reproduced the changes in prototype bed configurations for the 6-year verification period is considered adequate proof that the movement and deposition of bed material in the model constituted a satisfactory reproduction of the average movement and deposition in the prototype. Since the model satisfactorily reproduced prototype changes for the 6-year period in 36 tidal cycles, the model-to-prototype time scale for bed movement was established as six tidal cycles to one year, or 1.665 hours in the model to one year in the prototype. This time scale for bed movement was used in all subsequent tests of proposed improvement plans.

Errata Sheet

PLANS FOR IMPROVEMENT OF NAVIGATION CONDITIONS IN CORRAL BAY AND THE VALDIVIA RIVER, CHILE

TECHNICAL MEMORANDUM NO. 2-382, APRIL 1954

Page 22, paragraph 38. Please correct second sentence of paragraph to read:

> "Since the model satisfactorily reproduced prototype changes for the 6-year period in 36 tidal cycles, the model-to-prototype time scale for bed movement was established as six tidal cycles to one year, or 3.33 hours in the model to one year in the prototype.

PART V: NARRATIVE OF TESTS

Base Test

Purpose

39. The first test conducted in the model after completion of the hydraulic and bed-movement verification just described was a base test, or an extended test of existing prototype conditions. The purpose of the base test was twofold: (a) to establish the trends of movement and deposition of bed material throughout the problem area under existing conditions for a longer period of time than the verification period; and (b) to provide a basis with which to compare the results of subsequent tests of proposed improvement works. The results of the base test, when compared with the results of tests of similar duration involving proposed improvement works, will indicate the effects which the proposed improvement works will produce if installed in the prototype.

Description

40. The base test was started with the movable bed of the model molded to the prototype survey of 1946 (which was also the starting condition for all subsequent tests involving proposed improvement plans). It was agreed in conference with the Chilean Government Representative that tests of all improvement plans would be continued for a period of time equivalent to at least 12 years in the prototype; therefore, the base test was continued for 72 tidal cycles in the model, or the equivalent of 12 years in the prototype. Model operating conditions for the base test (tides, tidal currents, waves, etc.) were identical with those used for the model verification, and also identical with those used for all subsequent tests of proposed improvement plans.

41. Tidal phenomena for base-test conditions were observed at Los Molinos and Corral in Corral Bay, at Muelle de Pasageros and at the model extremity in the Valdivia River, and at the model extremity in the Tornagaleones River. These latter two gages are referred to hereinafter as the Cancaqual and Tornagaleones River gages, respectively. Current velocities were observed at station 1 near Muelle de Pasageros in the

Valdivia River, station 2 in the Tornagaleones River, station 3 in the channel between Mancera Island and Fronton, station 4 in the channel between Mancera Island and Carboneros, and stations 5 and 6 near the port of Corral in Corral Bay. The locations of tidal gages and current stations are shown on fig. 2. These data were used to evaluate the effects of each proposed plan of improvement on tidal elevations and times, and on current velocities throughout the area reproduced in the model. Time-exposure photographs were made of confetti moving on the model water surface, at strengths of both flood and ebb currents, at the end of the 12th year of the base test. These photographs delineate current directions throughout the problem area for existing conditions. Similar photographs taken during tests of improvement plans, when compared to those of the base test, show the effects of the various plans on current directions.

Results

42. A complete survey of the movable-bed portion of the model at the end of the 12-year base test is shown on plate 9, and the scour and fill that occurred between the beginning and end of this test are shown on plate 10. Comparison of these plates with plates 7 and 8, which show, respectively, the bed configurations at the end of the 6-year verification test and the scour and fill for that test, indicates that trends of movement and deposition of bed material noted during the 6-year verification test were for the most part continued during the 12-year base test. For example, encroachment of Three Sisters Shoal into the deep-water portion of the port of Corral was approximately twice as extensive for the base test as for the verification test. Continuation of this trend indicates that, unless a plan of improvement is adopted to halt the westerly movement of Three Sisters Shoal, the port of Corral will eventually become so restricted in width by this shoal that navigation therein will be impossible.

43. Surface current directions at strengths of flood and ebb currents in the base test are shown in photographs 1 and 2, respectively. Measurements of tidal elevations and current velocities throughout the model for base test conditions are not presented separately in this report; instead, these data are plotted against similar measurements

obtained during subsequent tests of proposed improvement plans, and are shown on all plates presenting tidal and current velocity data for the various plans tested.

Types of Improvement Plans Tested

44. All of the plans tested for improvement of conditions at the Valdivia River entrance and in the port of Corral involved installation of various types of structures intended to produce and maintain a navigable channel from the mouth of the Valdivia River to deep water in Corral Bay. One of the improvement plans, plan 2, involved structures designed to force the tidal prisms of the Valdivia and Tornagaleones Rivers to pass through the deep-water portion of the port of Corral. This plan was designed on the assumption that the increased tidal discharges through the port area would provide scouring velocities of such magnitude that deposition of sediment in the port area would be prevented.

45. Plans 1, 3, and 4 were designed to divert the Valdivia River entrance to the north and away from the port of Corral so that the river flow and sediment would enter Corral Bay a considerable distance from the port area. Each of these plans involved structures oriented in a westerly direction from the southern tip of Mancera Island to divert ebb flows from the Tornagaleones River and San Juan Bay toward the port of Corral so as to increase the velocities of ebb currents in the port area. Each of these plans also involved structures on the northern side of the relocated Valdivia River channel to constrict the channel cross section and to halt the southerly littoral drift along the east side of Corral Bay.

46. Plans 5, 6, and 7 were similar in principle to plans 1, 3, and 4; however, plans 5, 6, and 7 involved closure of the channel between Mancera Island and Fronton so that the tidal prisms of both the Valdivia and Tornagaleones Rivers would pass through the relocated Valdivia River channel in Corral Bay. These plans were designed to divert all fresh water entering Corral Bay away from the port of Corral, and to reduce

velocities in the port area to such extent that sediment could not be transported to the port area in appreciable quantities. These latter plans also involved structures to the north of the relocated Valdivia River channel to halt the southerly littoral drift along the east side of Corral Bay, but did not include structures to the west of Mancera Island.

Test Procedure

47. Each test was started with the movable-bed portion of the model molded to the prototype survey of 1946. For plans involving revisions of existing structures, such revisions were made prior to the beginning of the test. The new structures involved in each plan were installed in the model in increments during the first five years of each test. The schedule followed in installing the various increments of each plan was established by the Chilean Government Representative on the basis of estimated construction progress in the prototype. Revisions to existing structures, and the exact length of each plan structure installed during each of the first five years of the tests, are presented in table 1. The total lengths removed from existing structures, the plan structures installed during each of the first five years, the plan structures involved in each improvement plan, and the existing structures removed plus the plan structures installed for each improvement plan are summarized in table 2. The duration of each test was 72 tidal cycles in the model (12 years in the prototype). The movable-bed portion of the model was surveyed at the end of each 2-year period throughout the tests to permit determination of the progressive effects of each plan tested. Time-exposure photographs of confetti moving on the model water surface at strengths of flood and ebb currents were made at the end of each 12-year test. Measurements of tidal elevations and current velocities were made at the 5 tidal gages and 6 velocity stations shown in fig. 2 to determine the effects of each plan on tides and currents throughout the model. In addition, current velocities were measured in the improved channel across Corral Bay for

each plan to determine maximum flood and ebb velocities in the improved channel.

Plan 1

Description

48. The elements of improvement plan 1 consisted of structures M, N, O, P, and R as shown on plate 11. Prior to the beginning of the test of plan 1, the existing north and south jetties (structures A and Y) at the Valdivia River entrance and the existing dike at Carboneros were removed from the model and were replaced by structures O and P of plan 1. Structure P was installed during the first 2 years of the test, structure O during the first 3 years, structures M and N during the first 5 years, and structure R during the 4th and 5th years. The lengths of the structures were: structure M, 2953 ft; structure N, 5578 ft; structure O, 5315 ft; structure P, 6677 ft; and structure R, 4659 ft. The crest elevation of structures M, N, O, and R was +9.2 ft MLLW, while that of structure P was +3.6 ft MLLW.

Results

49. The configurations of the movable-bed at the end of the test of plan 1 are shown on plate 12, and the scour and fill that occurred during the 12-year test period are shown on plate 13. Photographs 3 and 4 show surface current directions throughout the problem area at strengths of flood and ebb currents, respectively, at the end of the test of plan 1. The effects of the plan on tidal elevations throughout the problem area are shown on plates 14 and 15, and its effects on current velocities are shown on plates 16 and 17.

50. Examination of plate 12 indicates that the controlling depth of the channel between the Valdivia River entrance and deep water in Corral Bay at the end of the test of plan 1 was of the order of 12 ft MLLW, or less than 3.0 meters. Since the controlling depth over the bar in Corral Bay is about 4.0 meters MLLW for existing conditions, it appears that plan 1 would afford no improvement over existing conditions insofar as the obtaining of a navigable channel across Corral Bay to the

Valdivia River entrance is concerned. Examination of plate 13 indicates that plan 1 caused fairly extensive deepening of the jettied channel as far as the seaward end of structure O; however, the sudden increase in width of the channel at this point permitted the formation of an extensive shoal between the seaward ends of structures M and N. Replacement of the existing south jetty at the Valdivia River entrance by structure P resulted in an increase in width of the river channel which permitted rather extensive shoaling of this channel upstream from sounding range 49.

51. There was no evidence that structure R of plan 1 increased ebb velocities at the port of Corral sufficiently to produce scour in this area. Comparison of the scour and fill map of plan 1 (plate 13) with that of the base test (plate 10) indicates that plan 1 prevented extensive encroachment of Three Sisters Shoal into the port area; however, it is believed that this effect was attributable to a reduction in the rate of supply of sediment to Three Sisters Shoal rather than to an increase in ebb scour in the port area. The orientation of the plan 1 structure was such that riverborne sediment was diverted away from the port of Corral by structure N, while the southerly movement of littoral drift along the east shore of Corral Bay was halted by structure M. The model test indicated that structures O and R of plan 1 had little, if any, effect on the over-all functioning of the plan.

52. Comparison of the base test and plan 1 tide curves on plates 14 and 15 indicates that the plan had no appreciable effect on tidal elevations or times throughout the area reproduced in the model. The principal effect noted was at Cancaqual gage, where low water elevation was raised about 0.2 to 0.3 ft. Comparison of the base test and plan 1 current velocity curves on plates 16 and 17 indicates that the plan reduced appreciably the ebb velocities at station 1, located in that section of the Valdivia River where removal of the existing south jetty and substitution of structure P resulted in an appreciable increase in channel width. Both flood and ebb velocities at station 4 were reduced slightly, indicating that reduction in width of the opening north of Mancera Island reduced tidal discharges through the opening. Flood

velocities were increased slightly at station 6 with no change in ebb velocities, while at station 5 ebb velocities remained unchanged and flood velocities were reduced slightly. Ebb velocities were reduced slightly at stations 2 and 3, while flood velocities at these stations were not affected by the plan. Velocity measurements made at an unnumbered station located in the center of the channel between structures O and N on sounding range 11 revealed a maximum ebb velocity of about 5.6 ft per second and a maximum flood velocity of about 3.6 ft per second.

53. Examination of the current-direction patterns for plan 1 (photographs 3 and 4) shows that, with minor exceptions, current directions were fairly uniform throughout the problem area. The current pattern at strength of flood indicated irregularities in flow alignment and the existence of eddies between the seaward ends of structures M and N, in the vicinity of the port of Corral, and between structure R and Mal Paso. Current directions at strength of ebb were as uniform as could be expected except possibly in the vicinity of Three Sisters Shoal where the current divided and passed around both sides of the crest of the shoal.

Discussion of results

54. The results of the model test of plan 1 indicate that the plan caused no drastic changes in existing hydraulic conditions throughout the problem area except in that portion of the Valdivia River in which the channel width was increased appreciably by the plan. The rate of encroachment of Three Sisters Shoal into the deep-water portion of the port of Corral would be greatly reduced by the plan, principally through a reduction in the rate of supply of sediment to the shoal. However, plan 1 would not provide the desired navigable depth in the channel connecting the Valdivia River entrance with deep water in Corral Bay. In fact, the controlling depth of this channel at the end of the test of plan 1 was about 1.0 meter less than the controlling depth of the existing channel.

Plan 2

Description

55. The elements of plan 2 are shown on plate 18. This plan

consisted of an 820-ft extension of existing structure A, an 8367-ft extension of existing structure Y, and installation of the 6300-ft-long structure N and the 2560-ft-long structure S. The crest elevation of structures N and S, and of the extension of structure Y was +9.2 ft MLLW, while the crest elevation of the extension of structure A was +3.6 ft MLLW. The extension of structure A was accomplished during the first year of the test, installation of structure N was accomplished during the first 3 years, extension of structure Y was accomplished in the first 5 years, and installation of structure S was accomplished during the 4th and 5th years of the test.

56. The structures of plan 2 were designed to provide the desired navigable depth across the central portion of Corral Bay by concentrating the flow of the Valdivia River between structure N and the extension of structure Y. Orientation of the seaward ends of structure N and the structure Y extension, and installation of structure S, was designed to concentrate the tidal discharges of the Valdivia and Tornagaleones Rivers and San Juan Bay through the port of Corral in an attempt to increase the depth and width of the deep-water portion of the port by increasing the scouring capacity of the tidal currents in that area.

Results

57. The condition of the movable bed at the end of the test of plan 2 is shown on plate 19, and the scour and fill that occurred during the 12-year test period are shown on plate 20. Photographs 5 and 6 show current directions at strengths of flood and ebb, respectively, at the end of the test of plan 2. The effects of the plan on tidal elevations are shown on plates 21 and 22, and the effects on current velocities are shown on plates 23 and 24.

58. Examination of plate 19 indicates that the controlling depth of the channel between structures N and Y at the end of the test of plan 2 was about 5.0 meters MLLW, which is only about 1.0 meter more than that of the existing channel across the bar. Examination of the scour and fill map for the test of plan 2 (plate 20) indicates that some scour occurred throughout the full length of the jettied channel but principally seaward from sounding range 14. An extensive fill occurred

in the deep-water portion of the port of Corral and along the east side of the access channel thereto, beginning at sounding range 10 near the dock facilities of the port and extending seaward to about sounding range 4. This fill resulted in a rather severe loss of width in the access channel to the port in the vicinity of Chorocamayo and Laurel, and caused scour of as much as 6 to 7 meters along the west side of the access channel in the vicinity of Laurel. It is probable, however, that depths and widths in this reach of the access channel were appreciably greater than required for navigation. Another very extensive fill developed north of the structure Y extension, caused by entrapment of the littoral drift by this structure, but this fill is of no significance since the area in which it occurred is of no importance to the functioning of the plan.

59. The current patterns shown on photographs 5 and 6 indicate very uniform flow directions throughout the problem area at strengths of both flood and ebb currents. The curvature of the seaward portion of the structure Y extension appeared to be extreme, since both flood and ebb current alignments departed somewhat from the alignment of the structure. The alignment of the ebb currents appears to have been responsible for scour along the west side of the access channel near Laurel as described above.

60. Tidal elevations throughout the model were not changed appreciably by plan 2 (plates 21 and 22), but the tide curves at both Muelle de Pasageros and Cancaqual indicate that the phasing of the tide in the Valdivia River was delayed slightly. Since the structures of plan 2 extended the mouth of the Valdivia River seaward an appreciable distance, a slight lag in the occurrence of tidal events in the Valdivia River was to be expected.

61. Flood current velocities (plates 23 and 24) were increased slightly and ebb velocities were reduced slightly at station 1 in the Valdivia River and station 2 in the Tornagaleones River. Both flood and ebb velocities were increased at station 3 in the channel between Mancera Island and Fronton, while both flood and ebb velocities were reduced at station 4 in the channel between Mancera Island and Carboneros. Both flood and ebb velocities were increased appreciably at station 5,

while velocities at station 6 were not changed by the plan. Velocity measurements made at approximately the center of the channel between structures N and Y on sounding range 12 indicated maximum ebb velocities of about 6.7 ft per second and maximum flood velocities of about 3.1 ft per second.

Discussion of results

62. The failure of plan 2 to provide the desired controlling depth between structures N and Y is probably attributable to the excessive width of this channel as compared to that of the channel between existing structures A and Y. The width between structures N and Y was increased on the assumption that a sufficient portion of the Tornagaleones River tidal prism would pass through the gap between Mancera Island and the seaward end of structure A extension to provide current velocities in the wider channel equal in magnitude to existing velocities between structures A and Y. However, examination of current velocity measurements at stations 3 and 4, and the current direction patterns on photographs 5 and 6 indicates that only a very small portion of the Tornagaleones River tidal prism passed through the gap north of Mancera Island. Instead, restriction of the width of this gap by the structure A extension diverted the Tornagaleones River flow away from this channel and through the channel between Mancera Island and Fronton.

63. The extensive filling of the deep-water portion of the port of Corral and the access channel thereto, between sounding ranges 4 and 10, appears to have been attributable equally to two major effects of plan 2. First, the material scoured from the channel between structures N and Y as installation of these structures progressed was transported directly to the port of Corral by the realigned ebb currents. Second, material supplied to the problem area by the Valdivia River, which probably deposits over a wide fan-shaped area of Corral Bay under existing conditions, was transported directly to the port area by the confining structures of plan 2. Even though current velocities in the port area were increased appreciably by plan 2, as evidenced by velocity measurements at station 5, the large increase in the supply of sediment to the port area more than offset the beneficial effects of the increased velocities,

with the net result that extensive filling occurred in the port area and along the east side of the access channel. Scour along the west side of the access channel was attributable to the increased velocities in the port area and encroachment of the shoal into the east side of the channel.

Plan 3

Description

64. The elements of plan 3 are shown on plate 25. The plan consisted of removal of the existing north and south jetties at the Valdivia River entrance and the existing dike at Carboneros, and installation of structures O, P, N, and R as shown on plate 25. The length of structure O was 8203 ft, that of structure N was 5479 ft, that of structure P was 6825 ft, and that of structure R was 2297 ft. The crest elevation of structures O, N, and R was +9.2 ft MLLW, while that of structure P was +3.6 ft MLLW. A gap about 500 ft wide was left in structure N, approximately 1000 ft west from the north tip of Mancera Island, to permit small craft plying between the port of Corral and the city of Valdivia to pass through structure N and thus avoid rough water that would be encountered if they were forced to pass around the seaward end of the structure.

65. Plan 3 was very similar in principle to plan 1 except that structure N was curved instead of straight, structure O was extended in length to replace both structures O and M of plan 1, and plan 3 incorporated the above-described gap in structure N to eliminate navigation hazards to small craft. Structures N and O were designed to deflect the Valdivia River away from the port of Corral and trap the littoral drift, while structure R was designed to increase ebb velocities in the deep-water portion of the port of Corral.

Results

66. Plate 26 shows the configurations of the movable bed at the end of the test of plan 3, while plate 27 shows the scour and fill that occurred during the 12-year test period. Plates 28 and 29 show the

effects of plan 3 on tidal heights throughout the problem area, while plates 30 and 31 show the effects of the plan on current velocities. Photographs 7 and 8 show surface current directions for plan 3 at strength of flood and ebb, respectively.

67. Examination of plate 26 indicates that the controlling depth of the improved channel at the end of the test of plan 3 was about 14 ft, or no greater than that of the existing channel across the bar. Plate 27 shows that extensive scour occurred in the navigation opening in structure N, indicating that a considerable portion of the Valdivia River tidal prism flowed through this opening instead of through the improved channel between structures N and O. Plate 27 also shows that appreciable filling occurred in the Valdivia River near Muelle de Pasageros, when replacement of existing structure A by structure P of plan 3 increased the width of the channel.

68. The effects of plan 3 on tidal elevations were negligible throughout Corral Bay and in the Tornagaleones River, but the phasing of tide was delayed somewhat in the Valdivia River, and the range of tide at Cancaqual was reduced slightly (plates 28 and 29). Plates 30 and 31 indicate that flood current velocities were increased slightly and ebb velocities were reduced slightly at stations 1 and 2. Flood velocities were increased slightly at station 3, while ebb velocities were not changed. Both flood and ebb velocities were reduced slightly at station 4, while velocities at stations 5 and 6 were not affected appreciably by the plan. Velocity measurements made at about the center of the channel between structures O and N on sounding range 11 indicated maximum ebb velocities of about 4.0 ft per second and maximum flood velocities of about 2.6 ft per second.

69. Photographs 7 and 8 indicate that current patterns throughout the problem area for plan 3 were very undesirable. At strength of ebb, all of the discharge passing through the gap between the end of structure P and Mancera Island, plus a portion of the discharge from the Valdivia River, flowed through the navigation opening in structure N. Flow through this opening at strength of flood produced crosscurrents in the Valdivia River adjacent to the opening that would probably be dangerous to

navigation. Rather extensive eddy action occurred between the seaward ends of structures O and N during the flood period as may be noted in photograph 7.

Discussion of results

70. The failure of plan 3 to provide the desired navigable depth in the improved channel is believed to be largely attributable to flow through the navigation opening in structure N. Water lost through this opening during both flood and ebb flow was needed to increase the scouring capacity of the currents in the channel between structures O and N. Furthermore, navigation of the opening by small craft would have been impossible except during or near the times of slack water because of the very strong current velocities in the opening.

71. Filling in the Valdivia River near Muelle de Pasageros was caused by the increase in width of the channel through this reach. A similar fill was noted during the test of plan 1, which involved an increase in channel width in this reach very similar to that of plan 3. Structure R of plan 3 was apparently ineffective in increasing current velocities in the vicinity of the port of Corral, as evidenced by velocity measurements at stations 5 and 6.

72. It is believed that plan 3 would reduce appreciably the present rate at which Three Sisters Shoal is encroaching into the deep water of the port of Corral, principally through a reduction in the rate of supply of sediment to the shoal. However, the plan would not provide a channel of the desired depth and width from deep water in Corral Bay to the Valdivia River entrance. The purpose of the navigation opening in structure N would be defeated because of strong currents in the opening except at or near times of slack water; furthermore, flow through this opening would set up crosscurrents and eddies in the Valdivia River that would be hazardous to navigation.

Plan 4

Description

73. The elements of plan 4 are shown on plate 32. This plan was

identical with plan 3, described in paragraphs 64 and 65, except that plan 4 did not incorporate a navigation opening in structure N, with the result that the total length of this structure was increased by 492 ft, and the length of structure R for plan 4 was 3281 ft as compared with a length of 2297 ft for plan 3. The purposes of the plan 4 structures, the crest elevation of each structure, and the order in which they were installed in the model were identical with the plan 3 structures described previously.

Results

74. Plate 33 shows the condition of the movable bed at the end of the test of plan 4, and plate 34 shows the scour and fill that occurred between the beginning and end of the test. The effects of the plan on tidal elevations are shown on plates 35 and 36, and its effects on current velocities are shown on plates 37 and 38. Surface current directions at strengths of flood and ebb, respectively, are shown in photographs 9 and 10.

75. Examination of plate 33 shows that the controlling depth of the channel between structures O and N was about -15 ft MLLW at the end of the test of plan 4. Although the controlling depth of this channel was only about one foot greater than that of plan 3, the width of the deeper portion of the channel was much greater for plan 4 than for plan 3. Plate 34 indicates that scour occurred generally over the entire area between structures O and N; however, the extent of the scour was not sufficient to produce the channel depth required for navigation.

76. The effects of plan 4 on tidal elevations throughout the problem area were negligible (plates 35 and 36). Both high and low water planes were lowered slightly at Cancaqual and Muelle de Pasageros in the Valdivia River, but tidal ranges and phases were not affected appreciably at any gage. Plates 37 and 38 indicate that plan 4 caused slight increases in flood velocities and slight decreases in ebb velocities at stations 1 and 2. Both flood and ebb velocities were increased at station 3 and reduced at station 4, indicating that a portion of the tidal discharge into and out of the Tornagaleones River was diverted from the channel between Mancera Island and Carboneros to the channel between Mancera

Island and Fronton. Velocities were not changed appreciably at station 5, but both flood and ebb velocities were increased slightly at station 6. Current patterns in the problem area (photographs 9 and 10) indicate that current directions for plan 4 were very good except between the seaward ends of structures O and N during flood, where flow around the end of structure O created an area of slack water on the channel side of this structure.

Discussion of results

77. The results of the model test of plan 4 indicate that this plan would reduce, or entirely eliminate, encroachment of Three Sisters Shoal into the deep-water portion of the port of Corral. However, the plan would not provide the desired navigable depth in the channel between structures O and N. Structure R caused slight increases in both flood and ebb velocities in the vicinity of the port of Corral, as evidenced by increases in both flood and ebb velocities at station 6, but not to an extent sufficient to cause scour in this area. On an over-all basis, it appears that plan 4 would not provide a satisfactory solution of all existing navigation problems in Corral Bay.

Review of Effectiveness of Plans 1-4

Purpose

78. Plans 1 through 4 were the only plans proposed for solution of the problems in Corral Bay at the time the model study was undertaken. The results of model tests of these plans indicated that no single plan would provide a satisfactory solution of all of the problems involved. Therefore, after completion of model tests of plans 1-4, an analysis was made of the model test results to determine the beneficial, detrimental, and ineffective features of each plan. It was thought that by combining the beneficial features of one or more of these plans, with possible alteration of such beneficial features to increase their effectiveness, a composite plan of improvement might be developed that would provide satisfactory solutions of all of the problems involved.

Results of analysis

79. Analysis of the results of the model tests of plan 2 indicated that the basic concept of increasing the depth and width of the anchorage area at the port of Corral by forcing the tidal and fresh-water discharges of the Valdivia and Tornagaleones Rivers to pass through the port area was not sound. The model test demonstrated that current velocities in the port area could be increased appreciably by this method, but that concentration of the sediment load of the Valdivia River into the port area, plus material scoured from between structures N and Y of plan 2, offset completely the beneficial effects of the increased velocities with the net result that shoaling in the port area was more severe for plan 2 conditions than for existing conditions. It is possible that the functioning of plan 2 might be improved temporarily by dredging a pilot channel between structures N and Y as construction of these structures progressed, which would eliminate sediment derived from this source; however, it is believed that such benefits would be of a temporary nature as long as the entire sediment load of the Valdivia was discharged into the port area by the structures of plan 2.

80. Plans 1, 3, and 4 were similar in principle in that each of these plans involved diversion of the Valdivia River away from the port of Corral so that the river discharged into Corral Bay well to the north of the port area, such diversion being accomplished by structure N of each plan. These plans also involved one or more structures to the east of structure N to train the currents in the new channel and prevent deposition of sediment therein derived from the southerly littoral drift (structures O and M of plan 1, and structure O of plans 3 and 4). Each plan also involved a structure oriented in an easterly direction from the southern tip of Mancera Island (structure R) which was designed to increase ebb scour in the vicinity of the port of Corral. Each plan involved replacement of existing structure A at the Valdivia River entrance by plan structure P, which served to divert the river currents into alignment with the relocated entrance channel and which also resulted in widening the Valdivia River channel downstream from Carboneros. These three plans all involved an opening between the seaward end of structure P and

Mancera Island, which was designed to divert a portion of the Tornagaleones River flow through the improved channel and thus provide greater scour therein.

81. Analysis of the results of model tests of plans 1, 3, and 4 indicated that structure N of each plan was by far the most effective structure in producing the desired results. The curved structure N of plans 3 and 4 appeared to function much better than the straight structure of plan 1, since both flood and ebb currents followed the alignment of the curved structure much better than that of the straight structure. Tests of the navigation opening in structure N of plan 3 indicated that such an opening would reduce the effectiveness of the over-all plans of improvement and would also constitute a hazard to navigation; therefore, the provision of a navigation opening in this structure, without locks, should be eliminated from consideration. Although structure N of plan 4 gave better results than that of plans 1 and 3, the model test results indicated that the length of the structure should be increased, because the channel depth at the seaward end of the structure for plan 4 (about -16 ft MLLW) was not adequate for navigation.

82. The model tests disclosed that structure O of plans 1, 3, and 4 had little effect on current alignments in the relocated channel, since the strongest currents tended to flow along structure N on the opposite side of the channel. In fact, it appeared that the net effect of structure O was detrimental rather than beneficial from this viewpoint, since flood currents around the seaward end of this structure caused either eddies or areas of slack water on the east side of the channel between the ends of structures O and N. Therefore, it was concluded that the only beneficial effect of structure O, or structures O and M in the case of plan 1, was to prevent movement of the southerly littoral drift into the improved channel. It appeared that a single structure located in the vicinity of structure M of plan 1 would serve this purpose in the most efficient and economical manner possible, and that this structure should be so aligned as to provide the greatest possible impounding area to the east of the structure.

83. Widening of the Valdivia River entrance, which resulted from

replacement of existing structure A by plan structure P, caused rather extensive filling in the widened portion of the channel; therefore, it was concluded that the width of this reach of channel should not be increased. The results of the model tests showed that flows through the channel between Mancera Island and Carboneros were decreased appreciably by plans 1, 3, and 4, indicating that flows into and out of the Tornagaleones River, instead of passing through the improved channel, were diverted to the channel between Mancera Island and Fronton. Consequently, it was concluded that, if the combined flows of both the Valdivia and Tornagaleones Rivers are required to produce the desired depth and width in the improved channel, which appears to be the case since the desired depth was not produced by any of the plans tested, the channel between Mancera Island and Fronton would have to be closed to prevent diversion of Tornagaleones River flow through that channel.

84. The model tests indicated that structure R of plans 1, 3, and 4 was completely ineffective. Although this structure did cause minor increases in current velocities in the vicinity of the port of Corral, the increases were not of sufficient magnitude to produce scour in the port area. Therefore, it was concluded that structures of this nature should be eliminated from consideration.

85. The above analysis indicated that a plan for solution of all existing navigation problems in Corral Bay should include the following general features: (a) a structure similar to structure N of plan 4, but extended in length to at least the present 6-meter depth contour in Corral Bay; (b) a structure located in the vicinity of Faro de Niebla to halt the southerly littoral drift along the east side of Corral Bay and thereby reduce the supply of sediment to the improved channel; (e) closure of the channel between Mancera Island and Fronton so that the combined flows of the Valdivia and Tornagaleones Rivers would pass through the improved channel, thus providing the greatest possible scouring potential; and (d) maintenance of the present channel width in the Valdivia River between existing structures A and Y to prevent extensive filling of that reach of channel. Plan 5 of the model study,was designed in accordance with the general features outlined above.

Plan 5

Description

86. The elements of plan 5 are shown on plate 39. This plan consisted of the following features: (a) removal of 1200 ft from the seaward end of existing structure Y prior to the beginning of the test, then addition of 600 ft to this structure in a curved direction during the first year of the test; (b) removal of 700 ft from the seaward end of existing structure A prior to the beginning of the test, then addition of 400 ft in a slightly curved direction during the first year of the test; (c) installation of the 1700-ft-long structure D during the first year of the test; (d) installation of the 1000-ft-long structure M during the second year of the test; (e) installation of the 7400-ft-long structure N in increments during the second through the fifth years of the test; and (f) installation of the 1000-ft-long structure F during the fifth year of the test. The crest elevations of structures M, N, F, and D and the curved extension of existing structure Y was +9.2 ft MLLW, while the crest elevation of the curved extension of existing structure A was +3.6 ft MLLW.

87. Structure N of plan 5 was designed to divert the flows of the Valdivia and Tornagaleones Rivers away from the port of Corral, and thus discharge the sediment load of these rivers into the deep water of Corral Bay as far as possible from the port, and also to confine and train the currents in such manner as to produce the desired navigable depth and width across the bar separating the Valdivia River entrance from deep water in Corral Bay. The purpose of structure D was to force the entire flows of both the Valdivia and Tornagaleones Rivers to pass through the improved channel, and thus provide the maximum scouring potential therein. Structure M was designed to halt the southerly littoral drift along the east side of Corral Bay and thus prevent deposition of such drift in the relocated channel. Structure F was designed to prevent the movement of sediment around the seaward end of structure N, because it was thought that such sediment might be carried upstream to the vicinity of the port of Corral, and also to protect the port area from storm waves from the

north. The seaward ends of existing structures A and Y were revised to improve flow conditions in that area.

Results

88. Plate 40 shows the condition of the movable bed at the end of the test of plan 5; plate 41 shows the scour and fill that occurred between the beginning and end of the test. Plates 42 and 43 show the effects of plan 5 on tidal elevations throughout the problem area, and plate 44 shows the effects on current velocities. Current directions at strengths of flood and ebb currents for plan 5 are shown on photographs 11 and 12, respectively.

89. Examination of plate 40 indicates that plan 5 provided a channel of at least 6 meters depth over a minimum width of about 400 ft from the seaward ends of existing structures A and Y to and slightly beyond the seaward end of structure N. However, a bar having a controlling depth over the crest of almost exactly -6 meters MLLW formed to the north of structure F and the seaward end of structure N. Plate 40 shows that maximum depths along the channel (east) side of structure N were of the order of -41 ft MLLW, which might be sufficiently great to endanger the stability of the structure.

90. Plate 41 indicates that scour occurred along the channel side of structure N between sounding ranges 7 and 14, and that rather extensive filling occurred to the east of structures N and F between sounding ranges 4 and 9. An extensive fill area developed to the west of structures N and F; however, most of this fill occurred during the first 5 years of the test, there being no appreciable fill in that area after completion of structure N and installation of structure F during the fifth year of the test. The area of fill east of structure M indicates that this structure fulfilled its purpose of halting the southerly littoral drift and preventing it from depositing in the relocated channel.

91. Plates 42 and 43 indicate that plan 5 caused slight delays in tidal phase in the Valdivia and Tornagaleones Rivers, and also caused a slight reduction in tidal range at Cancaqual in the Valdivia River. The elevations of both high and low water were lowered slightly at both Los Molinos and Corral, and the range of tide at Corral was increased slightly.

Flood current velocities were reduced and ebb velocities were increased at station 1, while flood currents were increased slightly and ebb currents were reduced slightly at station 2. Both flood and ebb currents were increased at station 4, which is located in the channel between Mancera Island and Carboneros. Current velocities at stations 3, 5, and 6 were reduced to such extent that accurate measurements at these stations were not possible; therefore, no velocity data for these stations are presented in this report. Velocities measured in the relocated channel at a point 500 ft east of structure N on sounding range 11 indicated maximum ebb velocities of 7.6 ft per second and maximum flood velocities of 1.8 ft per second.

Discussion of results

92. The results of the model test of plan 5 indicated that this plan would provide a channel at least 6 meters deep at MLLW from the present Valdivia River entrance to deep water in Corral Bay; however, navigation over the bar north of structure F and the seaward end of structure N might be hazardous because of the indefinite channel in this area. Extensive scour along the channel side of structure N in the vicinity of sounding ranges 9.5 and 10 might endanger the stability of the structure to some extent. It is believed that plan 5 would provide a navigable channel of the desired width and depth, and would prevent further encroachment of Three Sisters Shoal into the deep-water portion of the port of Corral; however, the extensive scour along the channel side of structure N indicated that the alignment of this structure should be changed to reduce current velocities adjacent to the structure. Although flood current directions in the realigned channel were satisfactory (photograph 11), the direction of the ebb currents (photograph 12) was such that they impinged on the central portion of structure N and produced extensive scour adjacent to that structure.

Plan 6

Description

93. The elements of plan 6 are shown on plate 45. This plan was

identical with plan 5, described in paragraphs 86 and 87, with the following exceptions: (a) the curvature of structure N was increased by shifting the center of this structure to the west in an effort to reduce the scour along the channel side of the structure noted during the test of plan 5, but the end locations of the structure were the same as those of plan 5 (increase in curvature resulted in an increase of 500 ft in length of structure N); (b) the length of structure F was increased from 1000 to 1200 ft; and (c) the lengths of existing structures A and Y were not decreased as in plan 5, but a curved 150-ft extension, having a crest elevation of +3.6 ft MLLW, was added to the end of existing structure Y to prevent movement of sediment around the seaward end of the structure. Structure M and the curved extension to existing structure Y were installed during the first year of the test, structure N was installed during the first five years, structure D was installed during the third year, and structure F was installed during the fifth year.

Results

94. The conditions of the movable bed at the end of the test of plan 6 are shown on plate 46, while the scour and fill that occurred during the 12-year test period are shown on plate 47. Plates 48 and 49 show the effects of the plan on tidal elevations throughout the problem area, and plate 50 shows the effects on current velocities. Surface current directions at strengths of flood and ebb for plan 6 are shown in photographs 13 and 14, respectively.

95. Examination of plate 46 indicates that plan 6 provided a channel of at least 6 meters depth over a minimum width of about 250 ft from the existing Valdivia River entrance to deep water in Corral Bay. This plate also shows that scour along the channel side of structure N was appreciably less than during the test of plan 5; the maximum depth adjacent to the structure for plan 6 was -35 ft MLLW, as compared to a depth of -41 ft MLLW for plan 5. Plate 47 shows that plan 6 caused extensive scour from the ends of existing structures A and Y seaward to sounding range 7.5 on the channel side of structure N. An appreciable fill area developed to the east of structure N between sounding ranges 3.5 and 9, but the fill area showed little tendency toward encroachment on the channel along

structure N. An extensive fill area developed to the west of the seaward end of structure N during the first 5 years of the test; however, little, if any, additional fill occurred in that area following completion of structure N and installation of structure F during the fifth year of the test. The fill area to the east of structure M indicates that this structure was effective in halting the southerly littoral drift before it reached the improved channel.

96. Plates 48 and 49 indicate that plan 6 had no appreciable effect on tidal elevations or phases throughout the problem area except that tidal phases were delayed slightly at Muelle de Pasageros and Cancaqual in the Valdivia River, and the range of tides was increased slightly at Corral. Current velocity curves on plate 50 reveal that ebb velocities were reduced and flood velocities were not affected at station 1, while neither flood nor ebb velocities were affected appreciably at station 2. Both flood and ebb velocities were increased at station 4. Velocity measurements at a point in the relocated channel about 450 ft east of structure N on sounding range 10 indicated maximum ebb velocities of about 5.7 ft per second and maximum flood velocities of about 1.8 ft per second. Photographs 13 and 14 show that current directions throughout the relocated channel were very uniform for both flood and ebb currents.

Discussion of results

97. The results of the model test of plan 6 indicated that this plan would afford a satisfactory solution of all existing navigation problems in Corral Bay for average conditions of river discharge. However, the depth of scour along structure N for average river discharge (maximum depth of -35 ft MLLW) suggested that extremely high river discharges might increase scour along the structure to such extent as to endanger the stability of the structure.

98. To obtain more definite information as to the effects of high river discharges on depth of scour along structure N for plan 6, a short supplementary test of this plan was made after completion of the normal 12-year test. In the supplementary test the fresh-water discharges of the Valdivia and Tornagaleones Rivers were increased to represent flood discharges. The results of this supplementary test indicated that such

discharge would increase the depth along the channel side of structure N to a maximum of about -47 ft MLLW, which might be sufficient to endanger the stability of the structure. It appeared that the high crest elevation (+9.2 ft MLLW) of the seaward ends of existing structures A and Y was the principal cause of the current attack on the central portion of structure N for the high discharge condition, and that lowering the crest elevation of the seaward ends of these structures would decrease the current attack on structure N.

Plan 7

Description

99. The elements of plan 7 are shown on plate 51. This plan was identical with plan 6, described in paragraph 93, except that the elevations of the seaward ends of existing structures A and Y were lowered as shown on plate 51. The revisions to existing structures A and Y were made prior to the beginning of the test. The purpose of these revisions was to facilitate the passage of high fresh-water discharges through the improved channel and prevent excessive scour along the channel side of structure N. The crest elevations of the remaining structures were identical with those of plan 6, and the order in which the various plan elements were installed was the same as for plan 6.

Results

100. The condition of the movable bed at the end of the 12-year test of plan 7 is shown on plate 52, and the scour and fill that occurred between the beginning and end of the test are shown on plate 53. Plates 54 and 55 show the effects of the plan on tidal elevations throughout the problem area, and plate 56 shows the effects on current velocities. Surface current directions at strengths of flood and ebb currents, respectively, are shown on photographs 15 and 16.

101. Examination of plate 52 indicates that plan 7 provided a channel of at least 6.0 meters depth at MLLW, over a minimum width of about 400 ft, from deep water in Corral Bay to and upstream from the seaward ends of existing structures A and Y at the Valdivia River entrance.

This plate also indicates that depths along the channel (east) side of structure N were nowhere great enough to endanger the stability of the structure. The greatest depth that developed in the improved channel was -55 ft MLLW (about -17 meters MLLW) on sounding range 13.5; however, this deep spot was located at almost the center of the channel between the seaward end of existing structure A and plan structure N, so the stability of the existing and plan structures was not endangered.

102. Examination of plate 53 indicates that plan 7 produced extensive scour in the improved channel from the ends of existing structures A and Y seaward to about sounding range 7. A rather extensive fill developed well to the east of structure N, beginning at about sounding range 9.5 and extending seaward to about sounding range 4; however, this fill area progressed seaward and showed no tendency toward encroachment on the channel along structure N. Plate 53 also shows a rather large area of fill west of structure N between sounding ranges 6.5 and 8.5, but all filling in this area occurred prior to completion of installation of structures N and F. No significant filling was noted to the west of these structures after their completion during the 5th year of the test. The fill to the east of structure M indicates that this structure fulfilled its purpose of halting the southerly littoral drift along the east side of Corral Bay. It appears that the impounding area east of structure M was essentially filled by the end of the 12-year test of plan 7; therefore, the length of structure M would probably have to be increased after about 12 years in order that the structure retain its effectiveness.

103. Comparison of the base test and plan 7 tide curves on plates 54 and 55 indicates that the plan had no appreciable effect on tidal elevations or phases except at Corral, where the range of tide was increased slightly and the planes of both high and low waters were lowered slightly. Current velocities at station 1 in the Valdivia River and station 2 in the Tornagaleones River (plate 56) were not changed appreciably by the plan. Both flood and ebb velocities were increased at station 4, which is located in the channel between Mancera Island and Carboneros. Velocities at stations 3, 5, and 6 were reduced to such extent that accurate measurements could not be obtained. Velocity measurements at a

station located about 450 ft east of structure N on sounding range 10 indicated maximum ebb velocities of about 6.1 ft per second and maximum flood velocities of about 2.2 ft per second in the improved channel.

104. The current patterns shown in photographs 15 and 16 disclose that flow conditions in the improved channel were very uniform at strengths of both flood and ebb currents. Comparisons of the lengths of confetti streaks in the improved channel with those throughout the remainder of Corral Bay will provide an indication of relative velocities throughout the problem area. This comparison shows that current velocities in the port area and access channel were quite weak as compared to those in the improved channel.

Discussion of results

105. The results of the model test of plan 7 indicate that this plan would provide satisfactory solutions of all existing navigation problems at the port of Corral and the Valdivia River entrance. The improved navigation channel into the Valdivia River provided by plan 7 was at least 6.0 meters deep at MLLW over a minimum width of about 400 ft, and the Chilean Government Representative considered this depth and width to be adequate for all vessels that would navigate the river channel to the city of Valdivia. Plan 7 would prevent further encroachment of Three Sisters Shoal into the deep-water portion of the port of Corral, since the plan eliminated all major sources of sediment to the shoal. The plan would not increase the width or depth of the port area; however, it is believed that the plan would prevent subsequent loss of any additional width or depth that might be obtained by dredging.

106. While a proper study of wave action is not possible in a model of the type used for the investigation reported herein, it is believed that plan 7 would provide adequate protection to the port of Corral from storm wave action. Structure F of plan 7 was designed for the dual purpose of preventing movement of sediment around the seaward end of structure N and protecting the port area from wave action. The first of these purposes is considered sufficiently important to justify construction of structure F, but it is also believed that the structure would be effective in reducing storm wave action in the port area.

107. As tested in the model, plan 7 made no provision for the safety of small craft navigating between the city of Valdivia and the port of Corral, since previous tests of a plan involving a navigation opening in structure N (plan 3) indicated that such an opening is not feasible (see paragraphs 69 and 72), because (a) current velocities in the opening at certain phases of the tide were too great for safe navigation through the opening, and (b) flows through the opening, especially during the ebb current phase, decreased the effectiveness of the plan in producing the desired navigable depth in the improved channel.

108. The Chilean Government Representative expressed the opinion that present wave action in Corral Bay is too severe for the safe passage of small craft around the seaward ends of structures N and F. Therefore, it is suggested that consideration be given to construction of a lock, possibly between the shore terminal of structure N and the north tip of Mancera Island, for the safe passage of small craft. Measurements made in the model indicate that the maximum difference in water-surface elevations on the east and west sides of the shore terminal of structure N would be about 0.75 ft, so that a gated structure of some type would be needed to permit traffic at all phases of the tide.

Extended Test of Plan 7

Purpose

109. A short supplementary test was made of plan 6, as described in paragraph 98, to determine the effects of high fresh-water discharges in the Valdivia and Tornagaleones Rivers on the functioning of the plan, with specific reference to the maximum depth of scour along the channel side of structure N. The results of this test indicated an appreciable increase in the depth of scour along structure N of plan 6; therefore, plan 7 involved revisions to the seaward ends of existing structures A and Y in an effort to reduce the intensity of current attack on structure N and thus reduce the extent of scour along the structure.

110. The results of the normal 12-year test of plan 7 showed less scour along structure N than did the normal test of plan 6 (maximum depth of -31 ft MLLW adjacent to structure N for plan 7, as compared to a

maximum depth of -35 ft for plan 6). After the normal test of plan 7 was completed, the fresh-water discharges of the Valdivia and Tornagaleones Rivers were increased to represent flood conditions, and a supplementary test of two years' duration was made to show the effects of the high discharge on scour adjacent to structure N.

Results

111. The results of the supplementary test of plan 7 are presented on plates 57 and 58. Plate 57 shows the condition of the movable bed at the end of the supplementary test, and plate 58 shows the scour and fill that occurred during the 2-year supplementary test. The duration of the supplementary test was much greater than any possible duration of flood conditions in the prototype; however, the test was continued for this length of time to indicate the maximum possible effects of flood discharges on the functioning of plan 7 if this plan should be constructed in the prototype.

112. Plate 57 indicates that the maximum depth adjacent to the channel side of structure N at the end of the supplementary test was -35 ft MLLW, as compared to a depth of -47 ft MLLW observed at the end of the supplementary test of plan 6. Plate 58 indicates that scour occurred generally throughout the length of the relocated channel, and fill occurred to the east of structure N between sounding ranges 3 and 9. Scour and fill shown on plate 58 occurred principally during the first year of the supplementary test; there was little change in bed conditions during the second year of the test, indicating that bed configurations reached a state of relative stability during the first year and remained stable throughout the remainder of the test.

Discussion

113. The results of the supplementary test of plan 7 indicate that flood conditions on the Valdivia and Tornagaleones Rivers would not cause such extensive scour along the channel side of structure N as to endanger the stability of the structure. The results also show that channel widths and depths observed at the end of the normal 12-year test were not impaired in any way by high river discharges. In fact, comparison of plates 52 and 57 indicates that the condition of the navigable channel of plan 7

was somewhat better at the end of the supplementary test than at the end of the normal test. It is believed that plan 7 would provide a satisfactory solution of all existing navigation problems in Corral Bay for both normal and extreme flow conditions in the Valdivia and Tornagaleones Rivers.

PART VI: CONCLUSIONS

114. The following conclusions are based on a complete analysis of the results of all tests conducted during the model investigation:

- a. Plan 7 of this report would provide a satisfactory solution of all existing navigation problems in Corral Bay. The plan would not increase the width and depth of the deep-water portion of the port of Corral, but would prevent subsequent loss of any additional width or depth that might be obtained by dredging. The plan would provide a channel of adequate width and depth for navigation from deep water in Corral Bay to the existing Valdivia River entrance, and would have no detrimental effects on the Valdivia River channel upstream from the existing entrance. The plan should also afford adequate protection to the port of Corral from storm waves from the north. It is of interest to note that construction of plan 7 in the prototype would require revision to 1900 ft of existing structures and installation of a total of 11,950 ft of plan structures. In comparison, plan 2 would require installation of a total of about 18,050 ft of plan structures, while plan 4 would require removal of about 10,000 ft of existing structures and installation of a total of 24,280 ft of plan structures.

- b. The failure of plans 1, 3, and 4 to provide the desired improvements was due principally to the inadequate length and improper location of structure N of these plans, together with failure of the Tornagaleones River flow to pass through the relocated channel. In the case of plan 3, the functioning of the plan was further impaired by flow through the navigation opening in structure N.

- c. The principal reason for failure of plan 2 was that the training structures of this plan concentrated the entire sediment load of the Valdivia River in the deep-water portion of the port of Corral. Although plan 2 caused substantial increases in current velocities in the port area, the large increase in the supply of sediment to the area more than offset the beneficial effect of the increased velocities, with the net result that sedimentation in the port area was more severe for plan 2 conditions than for existing conditions.

PART VII: ACKNOWLEDGMENTS

115. The Valdivia River model study was carried out by the Estuaries Section, Rivers and Harbors Branch, Hydraulics Division, of the Waterways Experiment Station, Corps of Engineers, Vicksburg, Mississippi. The study was begun under the direction of Colonel H. J. Skidmore, CE, Director, Waterways Experiment Station. It was completed and this report was prepared under the direction of Colonel C. H. Dunn, CE, Director. The study was carried out under the supervision of Mr. J. B. Tiffany, Assistant Director of the Waterways Experiment Station, and Mr. E. P. Fortson, Jr., Chief of the Hydraulics Division. Waterways Experiment Station engineers actively concerned with the model study were: Messrs. G. B. Fenwick, Chief of the Rivers and Harbors Branch; H. B. Simmons, Chief of the Estuaries Section; H. J. Rhodes, engineer in direct charge of the model study; and assistants W. A. Moore, L. W. Matthews, M. B. Schultz, and R. W. Brumitt.

116. Special acknowledgment is offered for the assistance of Engineer Carlos Rodriguez, Representative of the Chilean Government, who was assigned to the Waterways Experiment Station for the duration of the model study. His intimate knowledge of the prototype was of great value throughout the course of the study.

<u>Table 1</u>

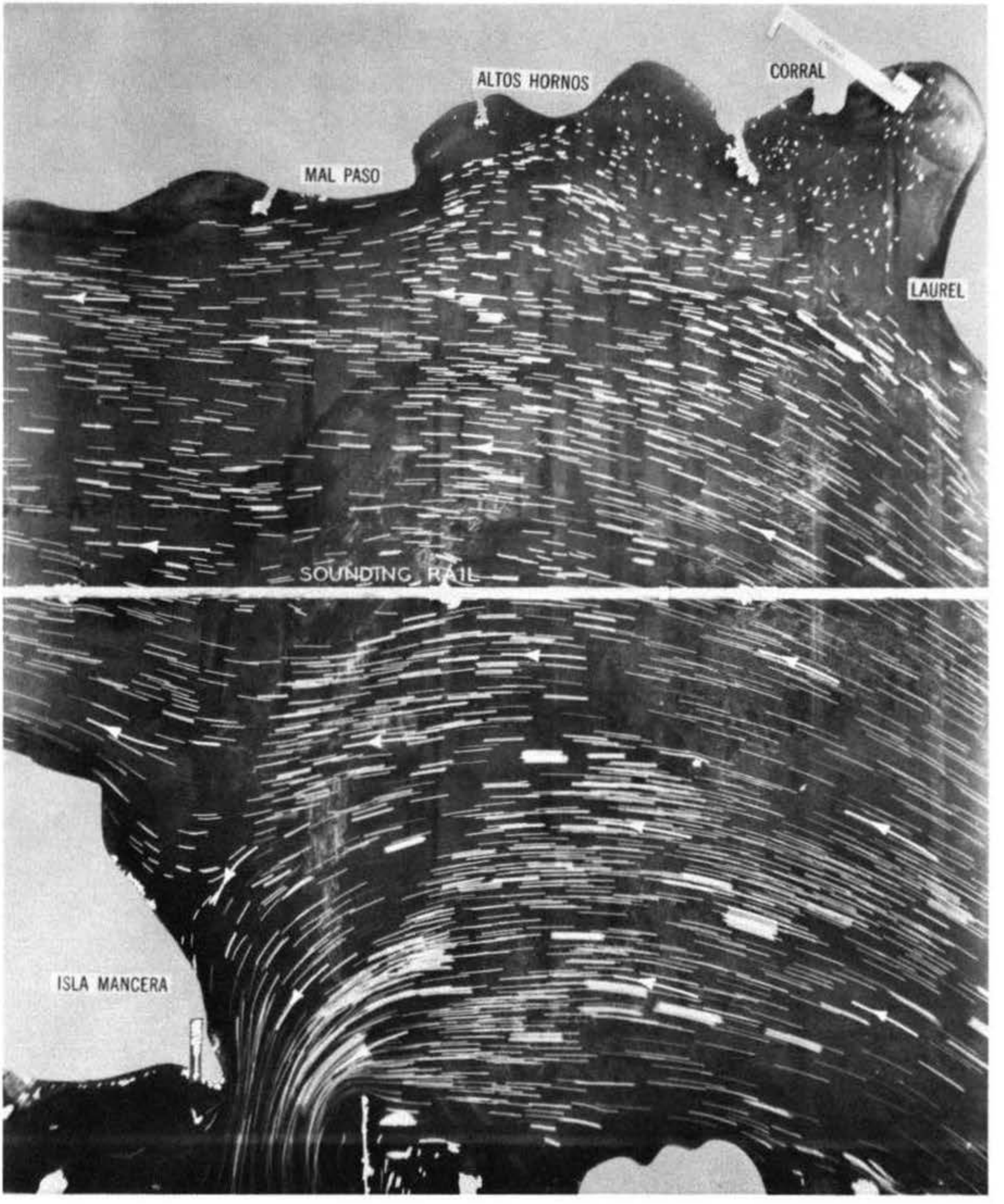
SCHEDULE FOR REVISION OF EXISTING STRUCTURES
AND INSTALLATION OF PLAN STRUCTURES

Plan No.	Existing Structures Removed Prior to Beginning of Test	Lengths of Plan Structures Installed during Each Year, in feet				
		1	2	3	4	5
1	Structure A	M, 656	M, 656	M, 656	M, 656	M, 329
	Structure Y	N, 657	N, 985	N, 1312	N, 1312	N, 1312
	Dike at Carboneros	O, 445	O, 1870	O, 3000		
		P, 3150	P, 3527			
					R, 2362	R, 2297
2	None	A, 820				
		Y, 1673	Y, 1673	Y, 1673	Y, 1674	Y, 1674
		N, 2100	N, 2100	N, 2100		
					S, 1280	S, 1280
3	Structure A	N, 1017	N, 721	N, 1247	N, 1247	N, 1247
	Structure Y	O, 984	O, 1805	O, 1805	O, 1969	O, 1640
	Dike at Carboneros	P, 3741	P, 3084			
				R, 2297		
4	Structure A	N, 1017	N, 1213	N, 1247	N, 1247	N, 1247
	Structure Y	O, 984	O, 1805	O, 1805	O, 1969	O, 1640
	Dike at Carboneros	P, 3741	P, 3084			
				R, 3281		
5	700 ft of structure A	A, 400				
			M, 1000			
			N, 2100	N, 2100	N, 2000	N, 1200
	1200 ft of structure Y	Y, 600				
		D, 1700				
						F, 1000
6	None	Y, 150				
		M, 1000				
		N, 100	N, 2000	N, 2100	N, 2500	N, 1200
				D, 1700		
						F, 1200
7	None	Y, 150				
		M, 1000				
		N, 100	N, 2000	N, 2100	N, 2500	N, 1200
				D, 1700		
						F, 1200

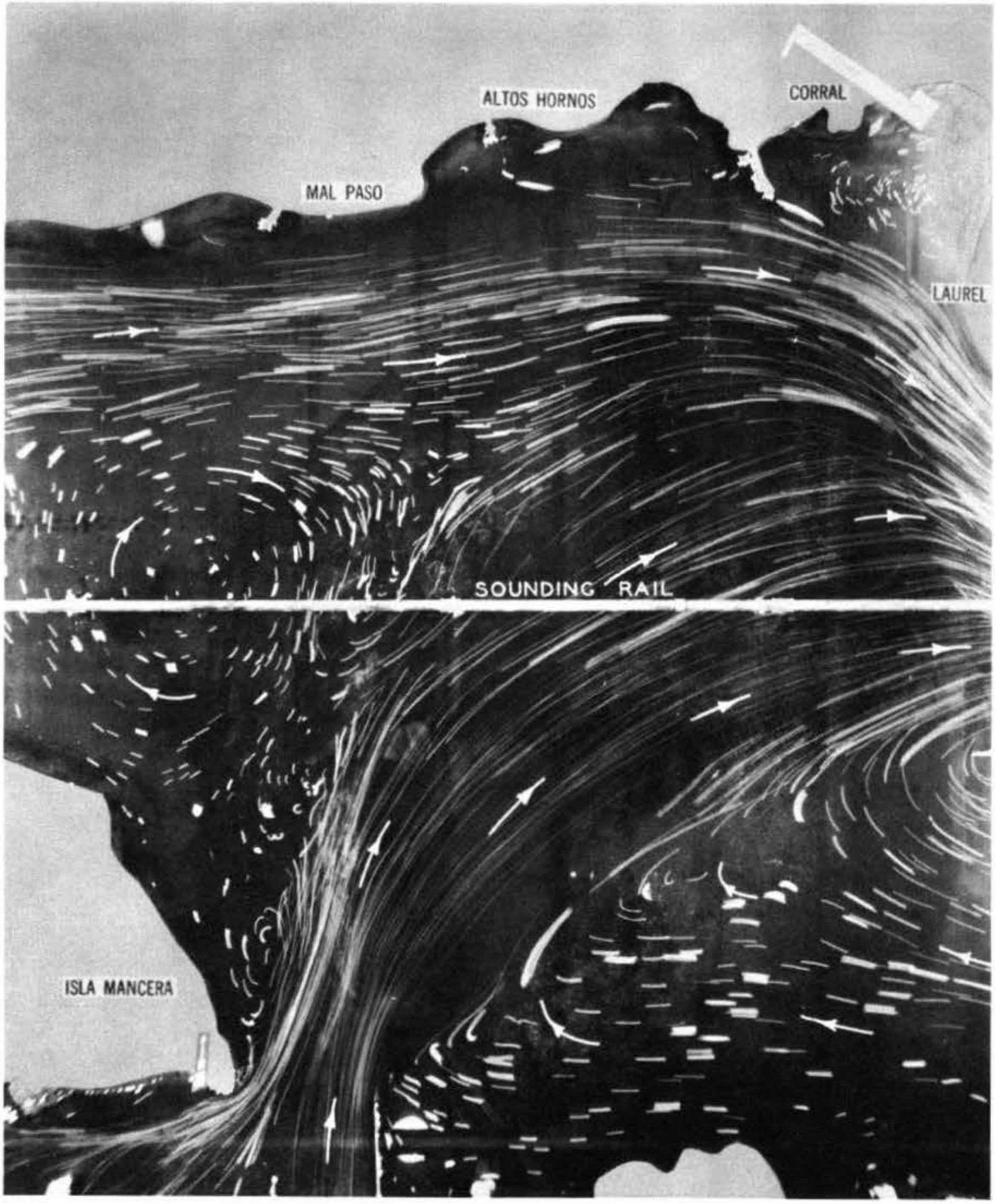
Table 2

CONSTRUCTION REQUIREMENTS FOR PROPOSED IMPROVEMENT PLANS

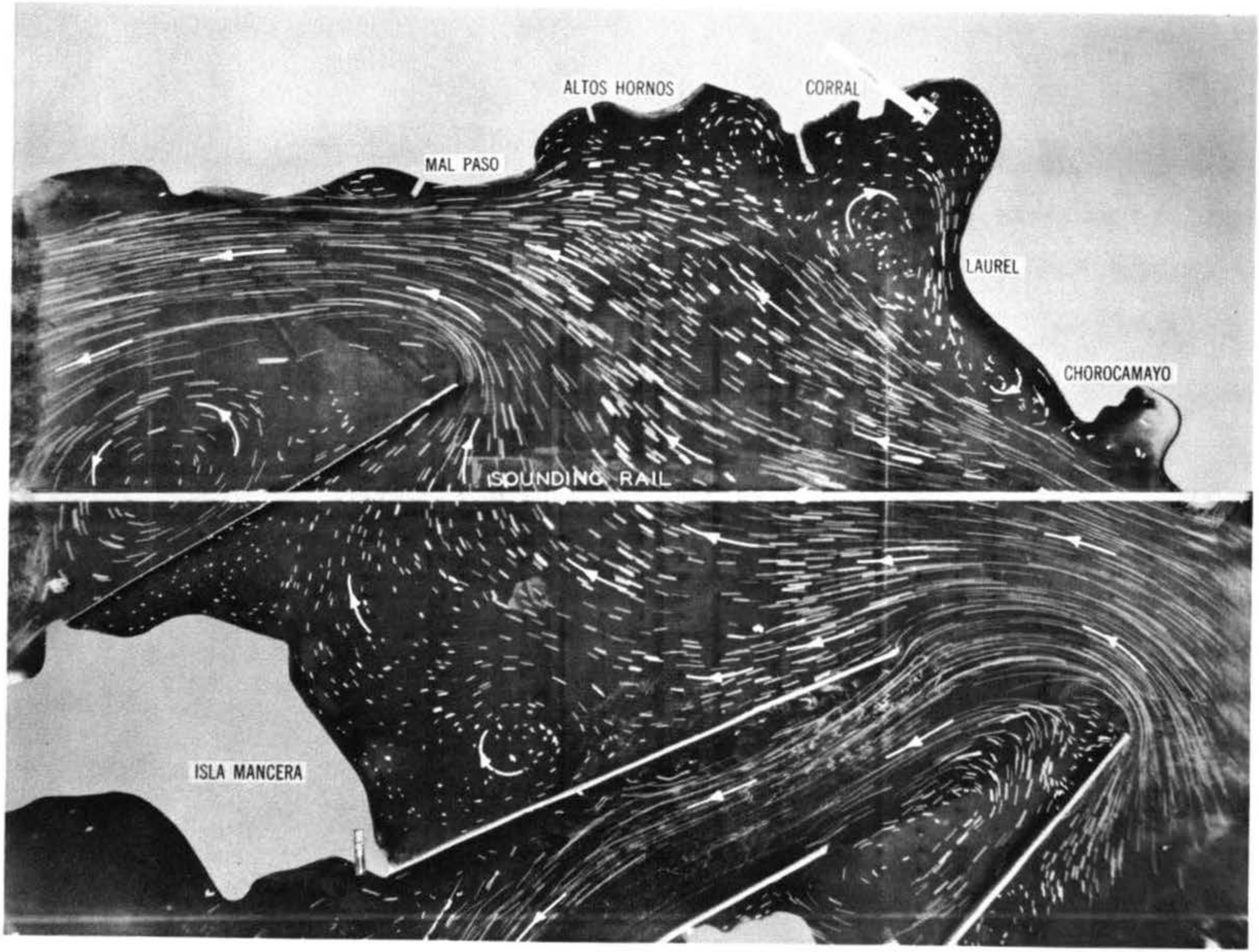
Plan No.	Total Length of Existing Structures Removed Prior to Beginning Test (ft)	Total Length of Plan Structures Installed during Each Year (ft)					Total Length of Plan Structures Installed (ft)	Total Length of Structures Removed and Installed (ft)
		1	2	3	4	5		
1	10,004	4908	7038	4968	4330	3938	25,182	35,186
2	None	4593	3773	3773	2954	2954	18,047	18,047
3	10,004	5742	5610	5349	3216	2887	22,804	32,808
4	10,004	5742	6102	6333	3216	2887	24,280	34,284
5	1,900	2700	3100	2100	2000	2200	12,100	14,000
6	None	1250	2000	3800	2500	2400	11,950	11,950
7	None	1250	2000	3800	2500	2400	11,950	11,950



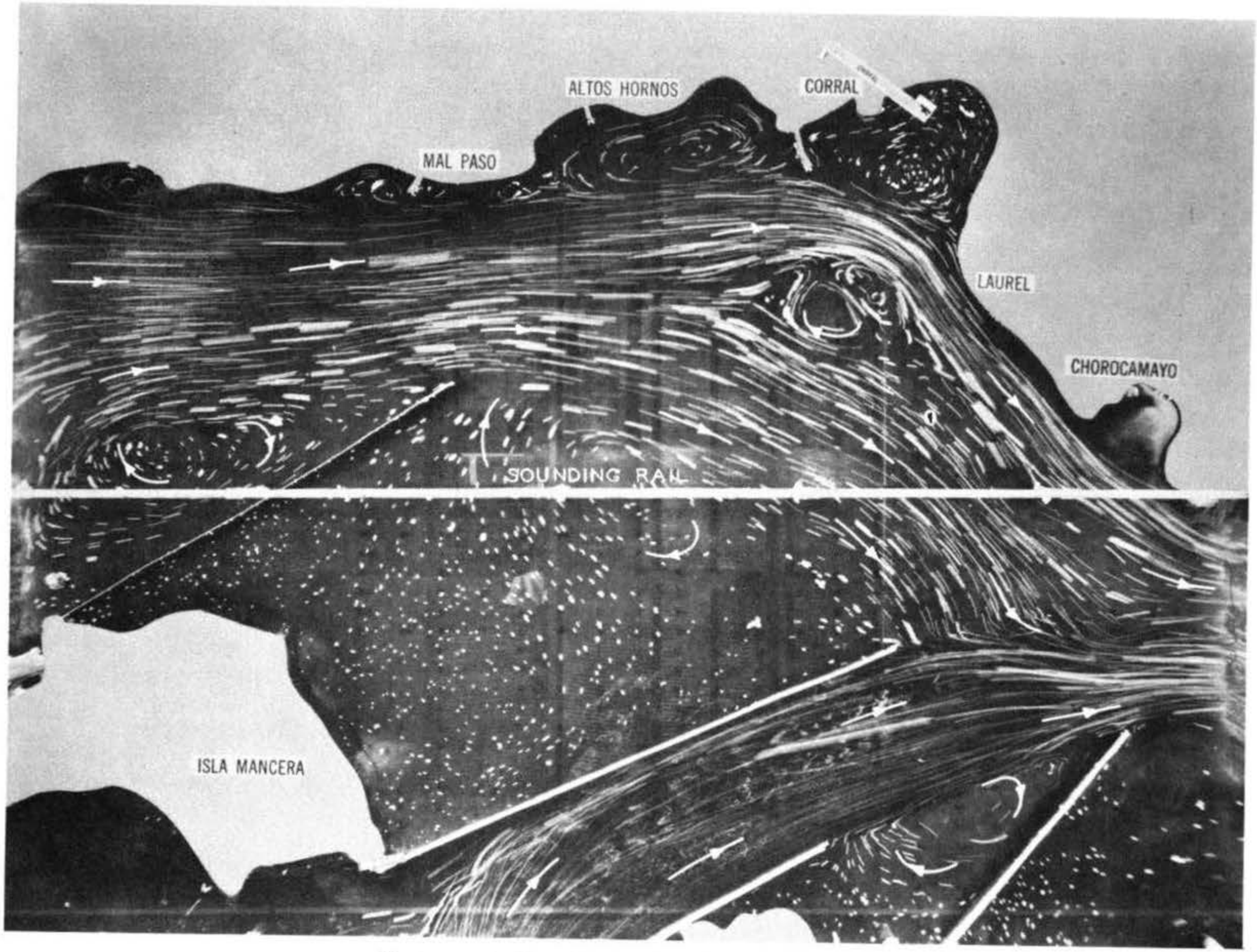
Photograph 1. Strength of flood, base test



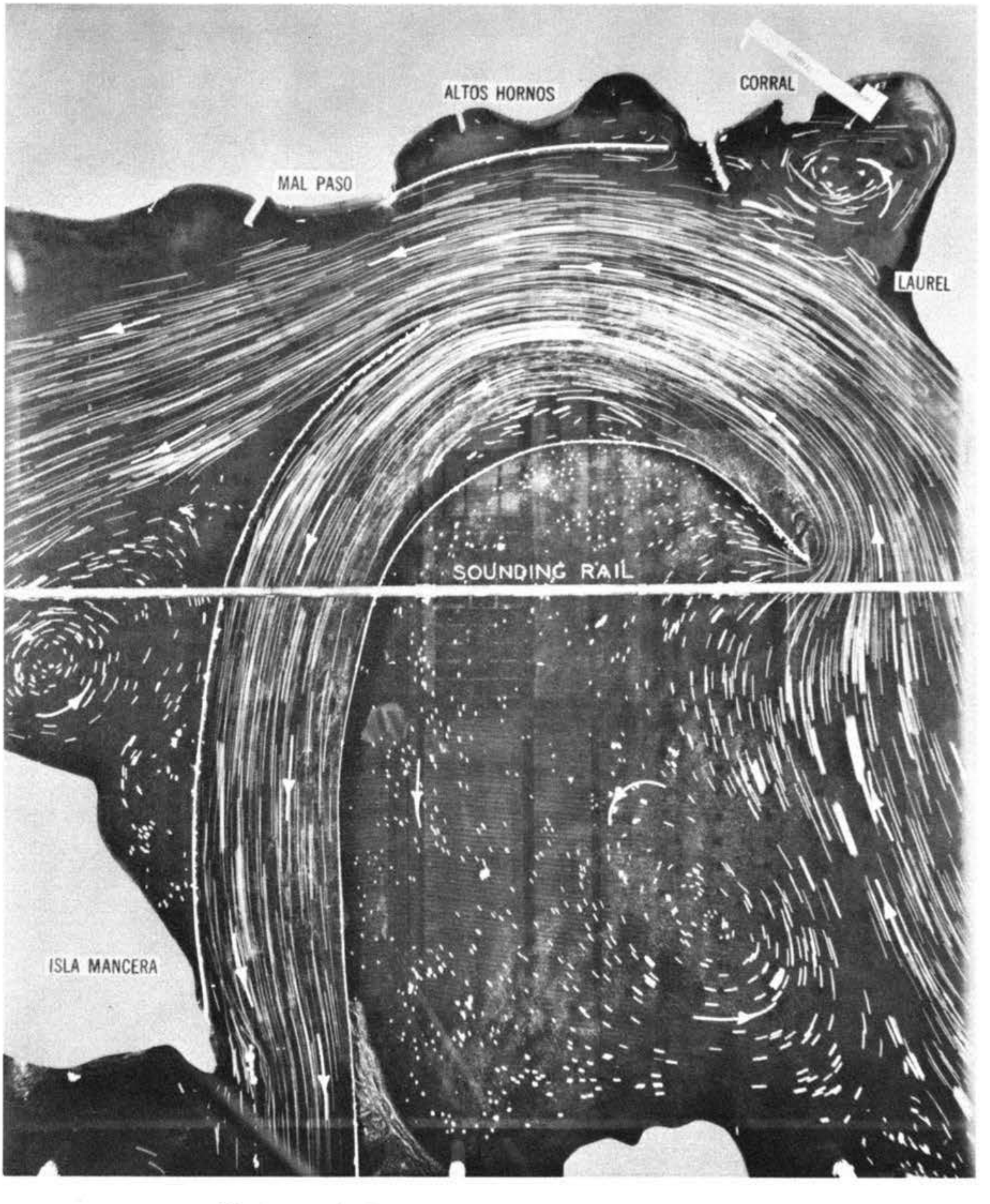
Photograph 2. Strength of ebb, base test



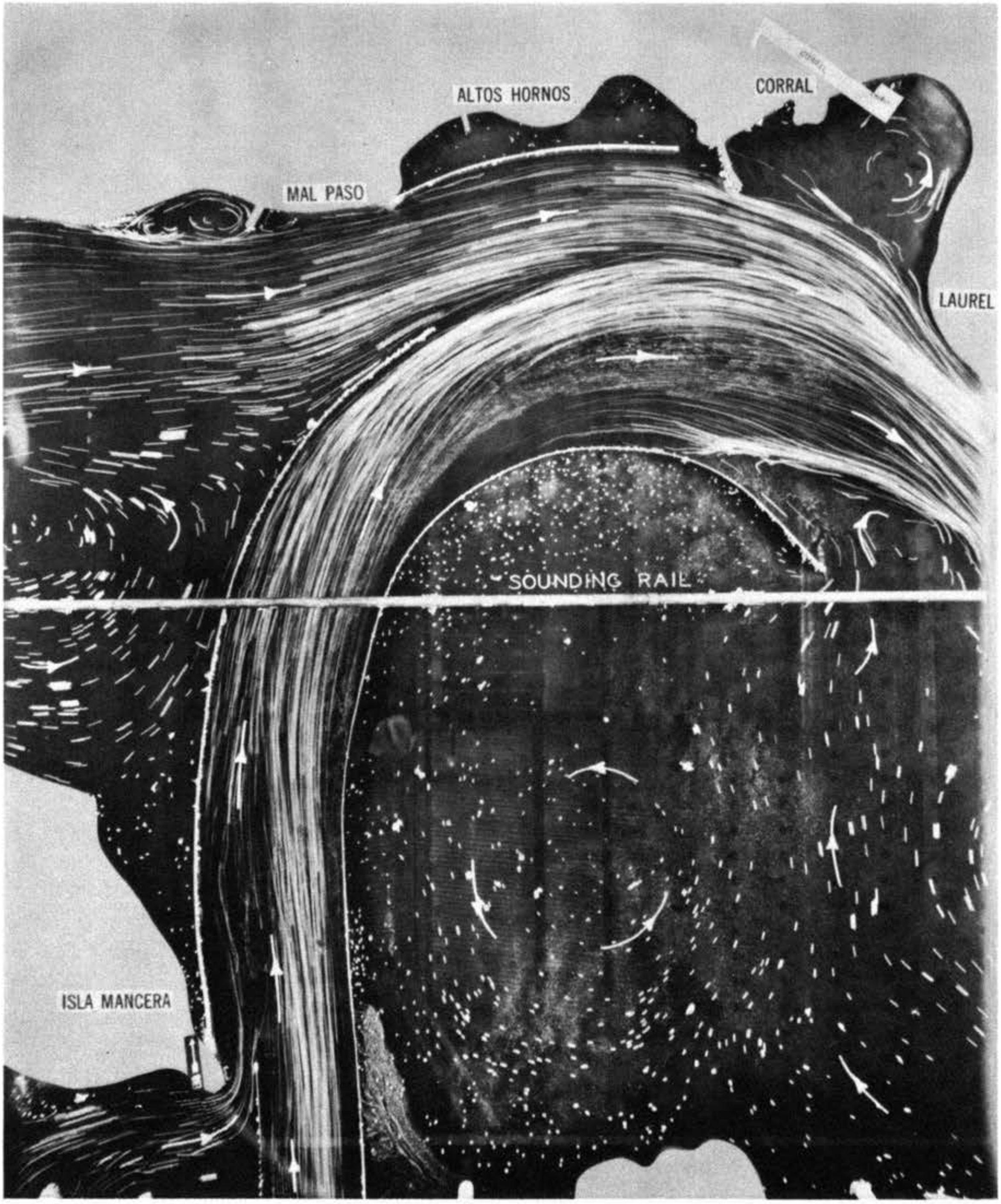
Photograph 3. Strength of flood, plan 1



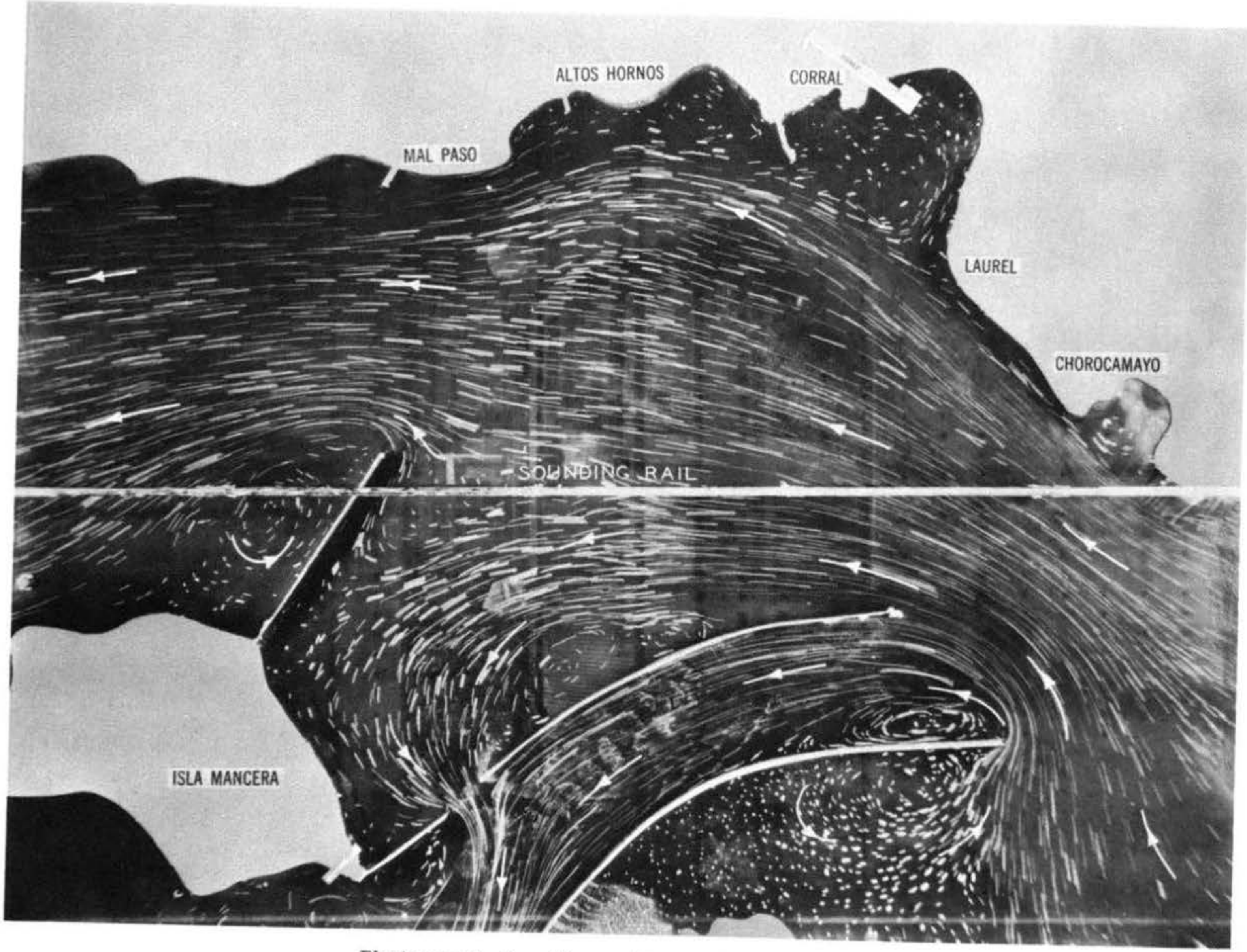
Photograph 4. Strength of ebb, plan 1



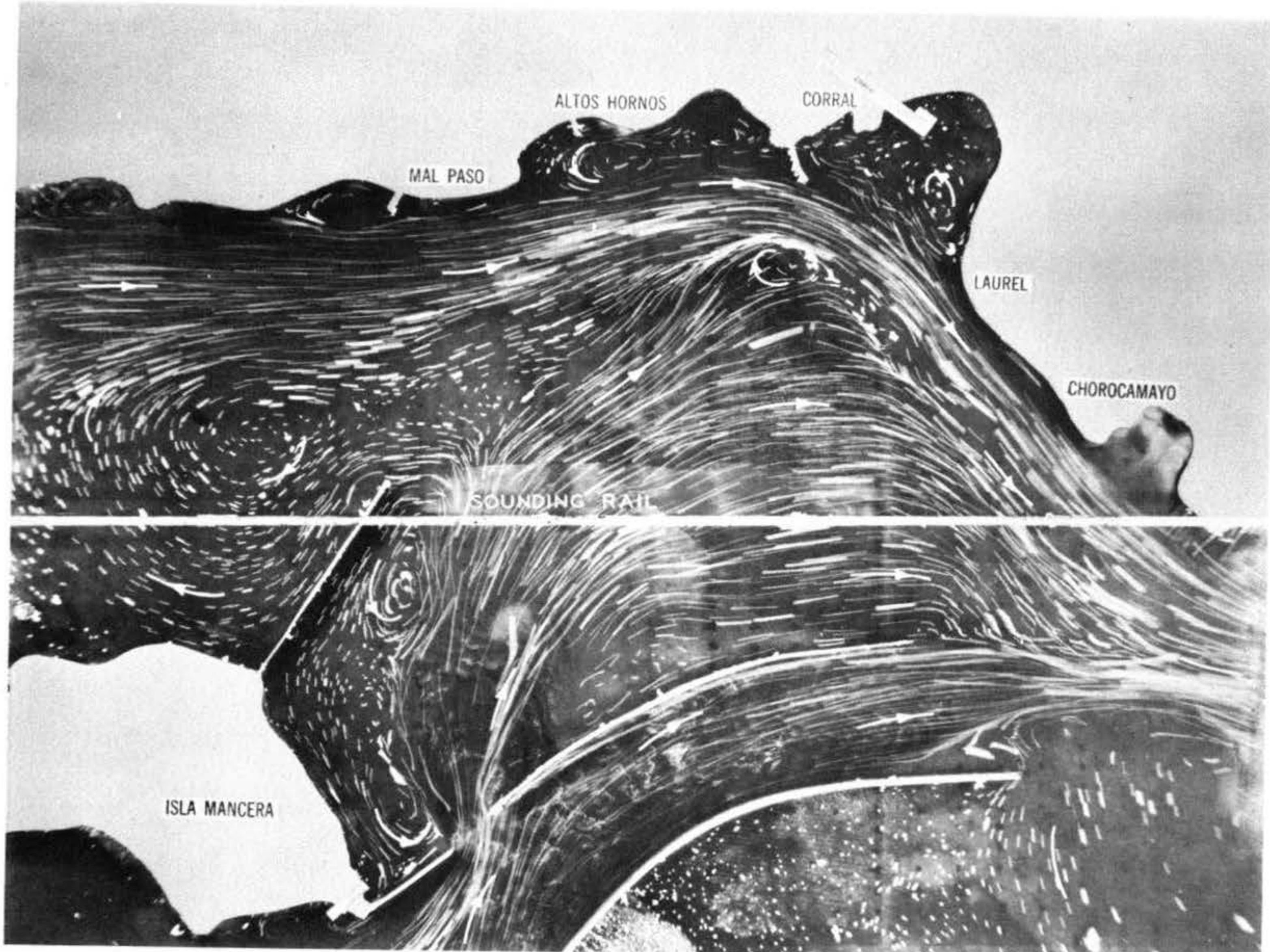
Photograph 5. Strength of flood, plan 2



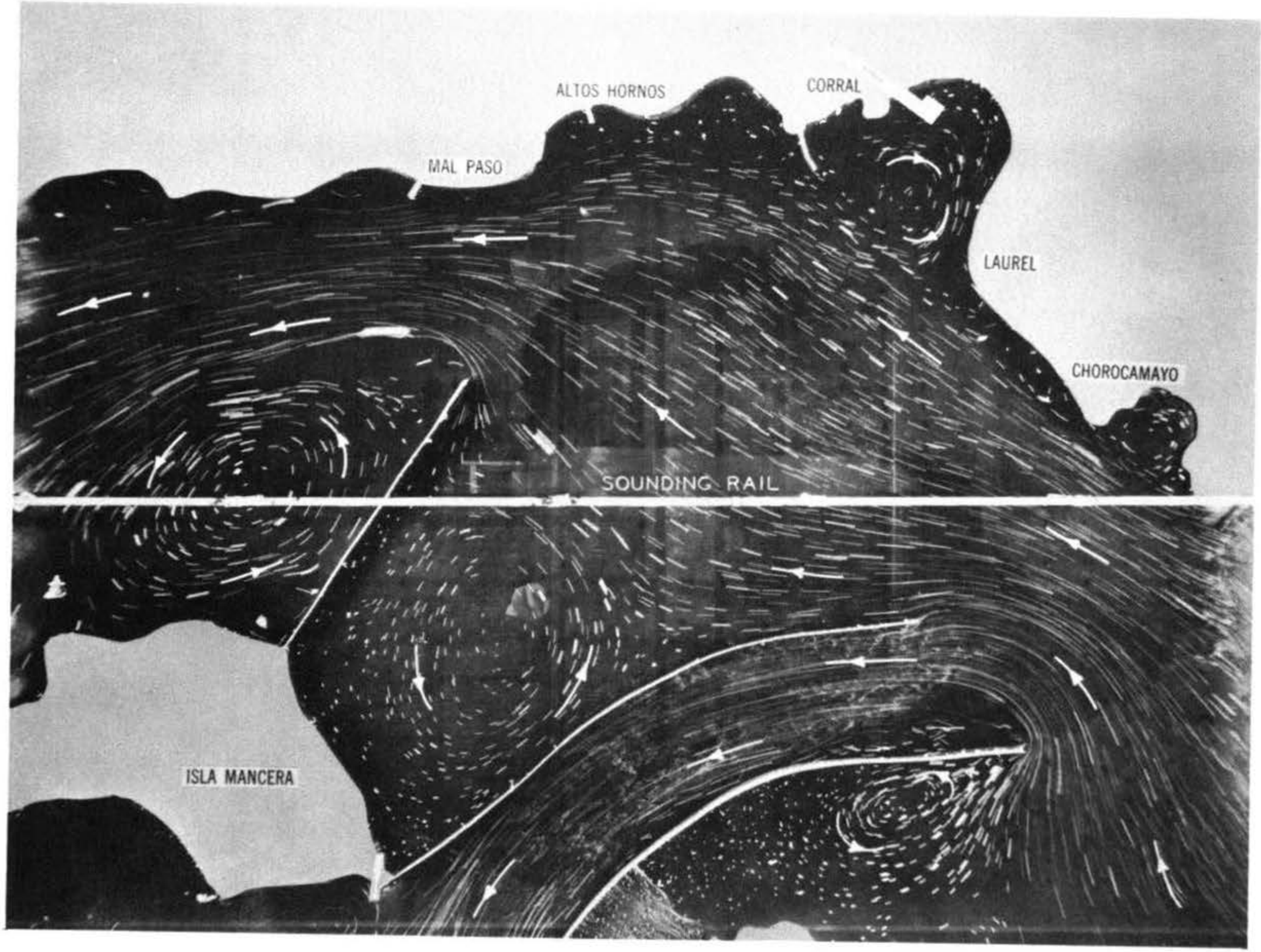
Photograph 6. Strength of ebb, plan 2



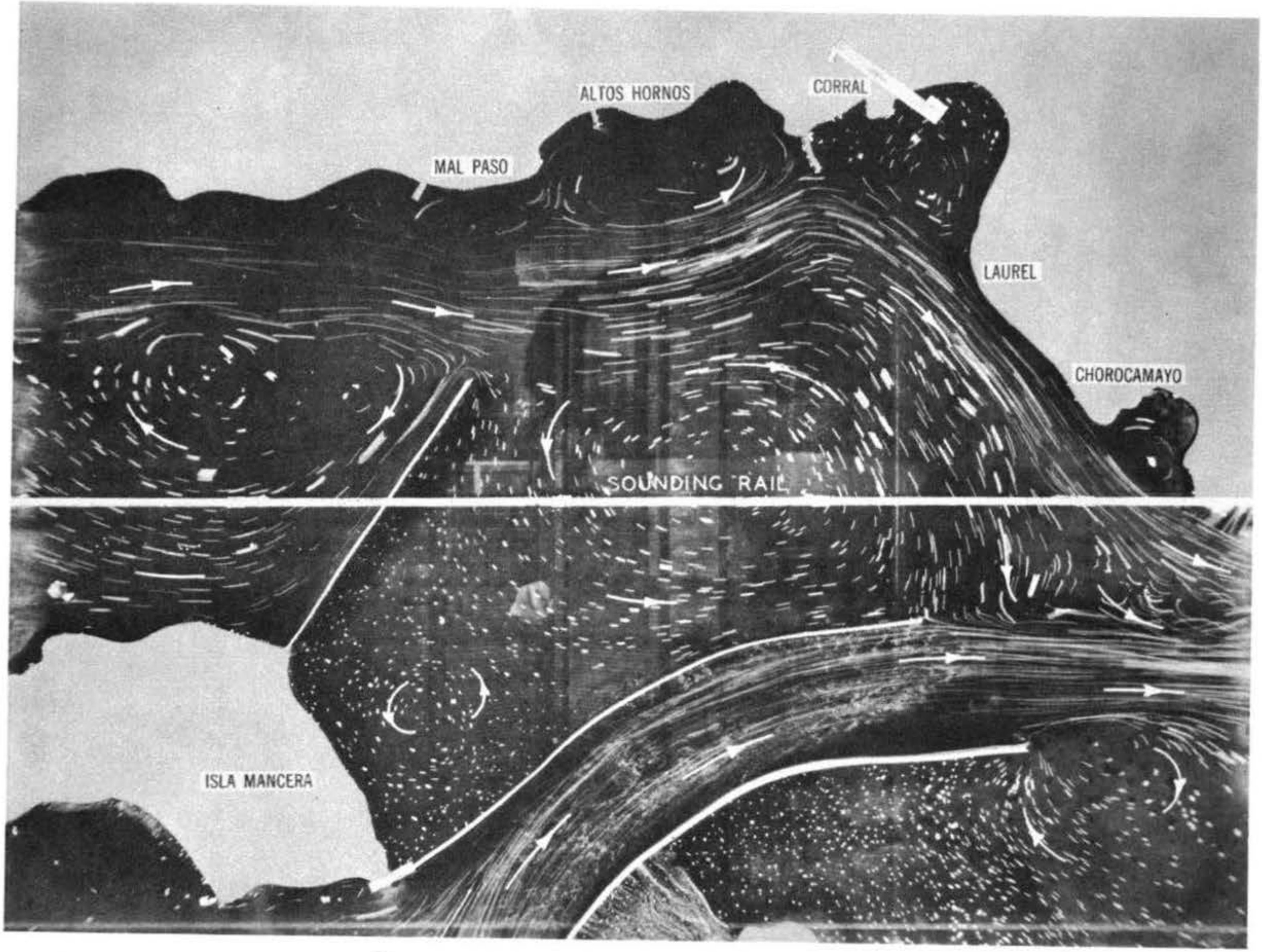
Photograph 7. Strength of flood, plan 3



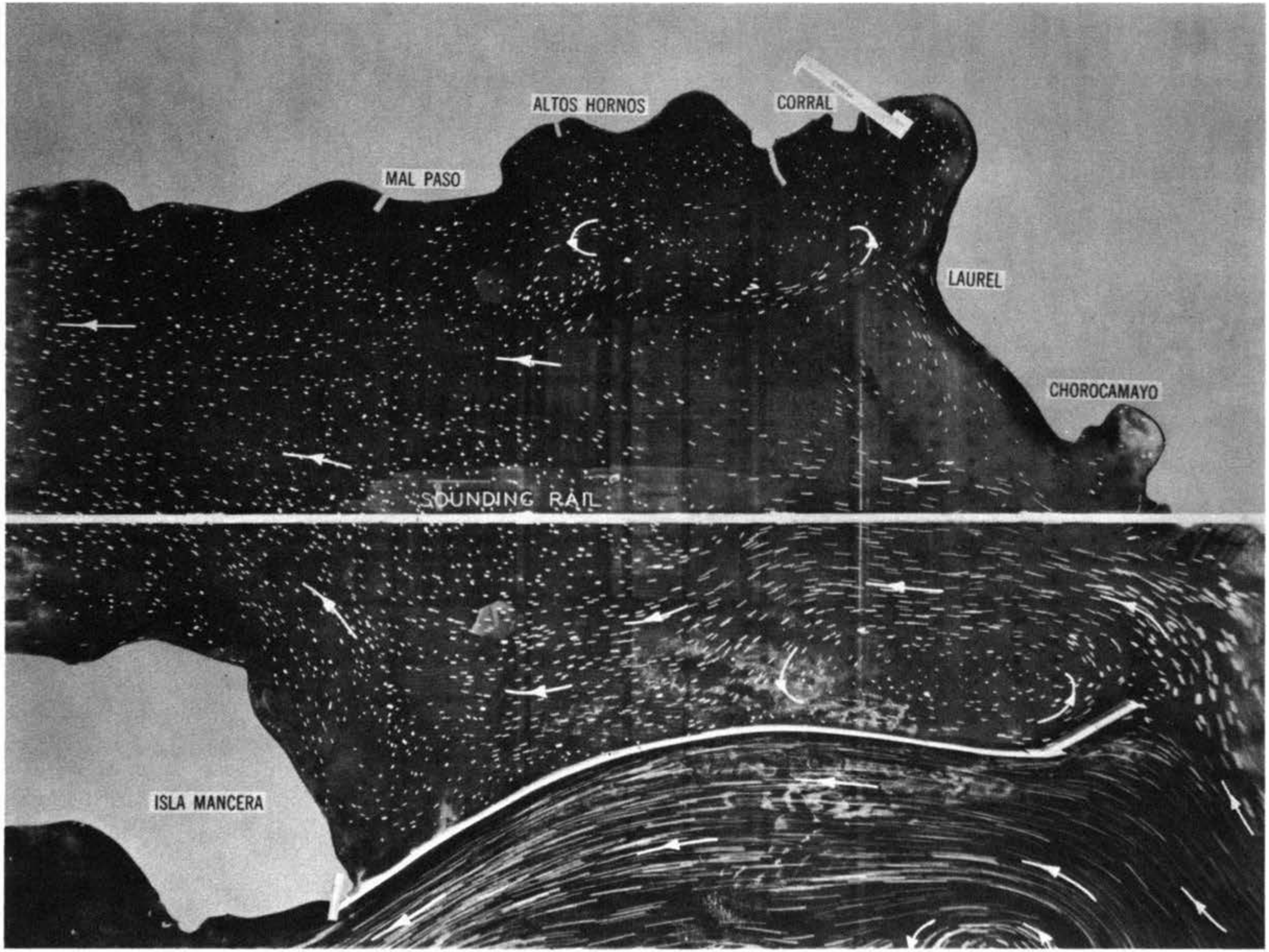
Photograph 8. Strength of ebb, plan 3



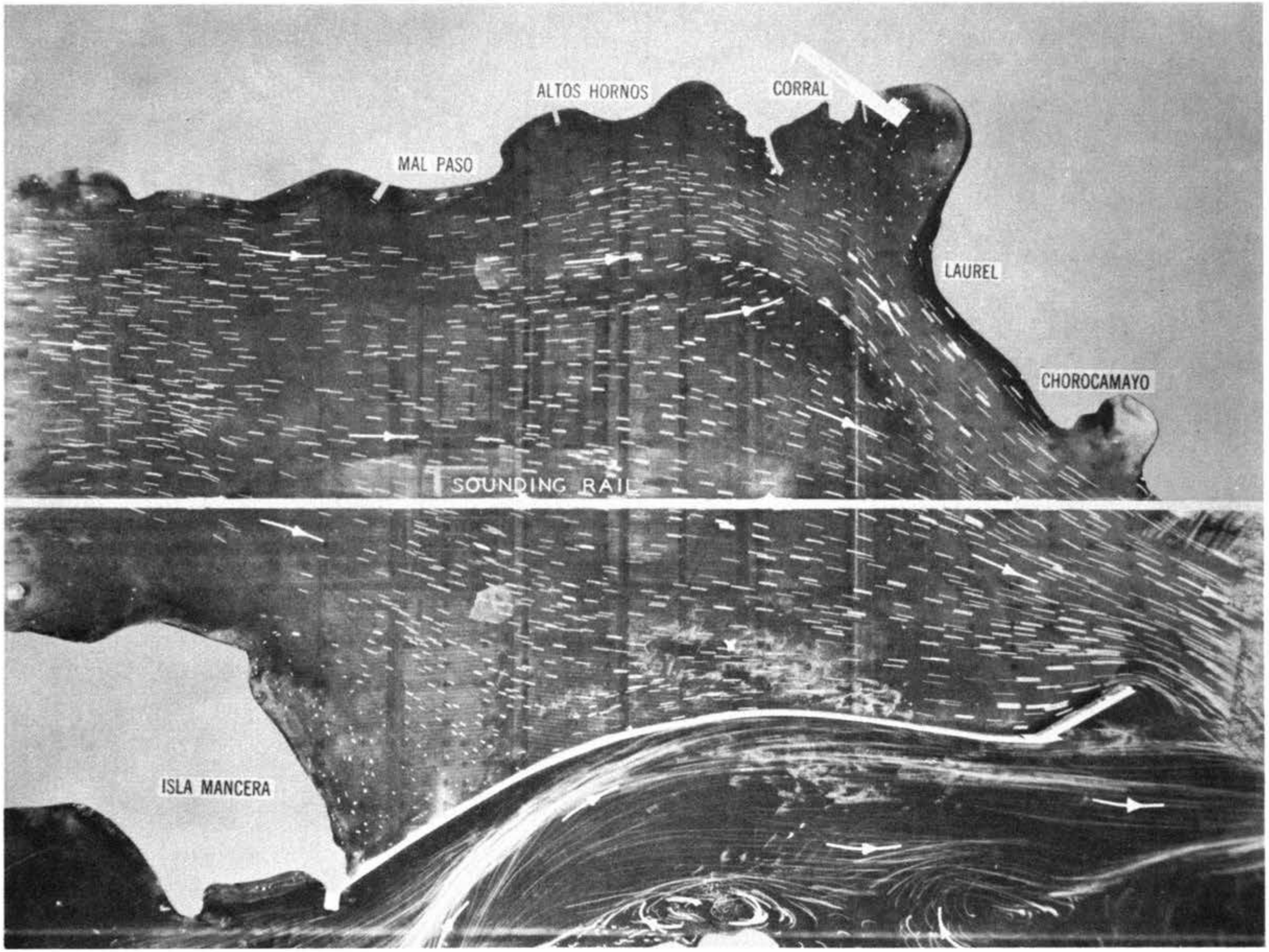
Photograph 9. Strength of flood, plan 4



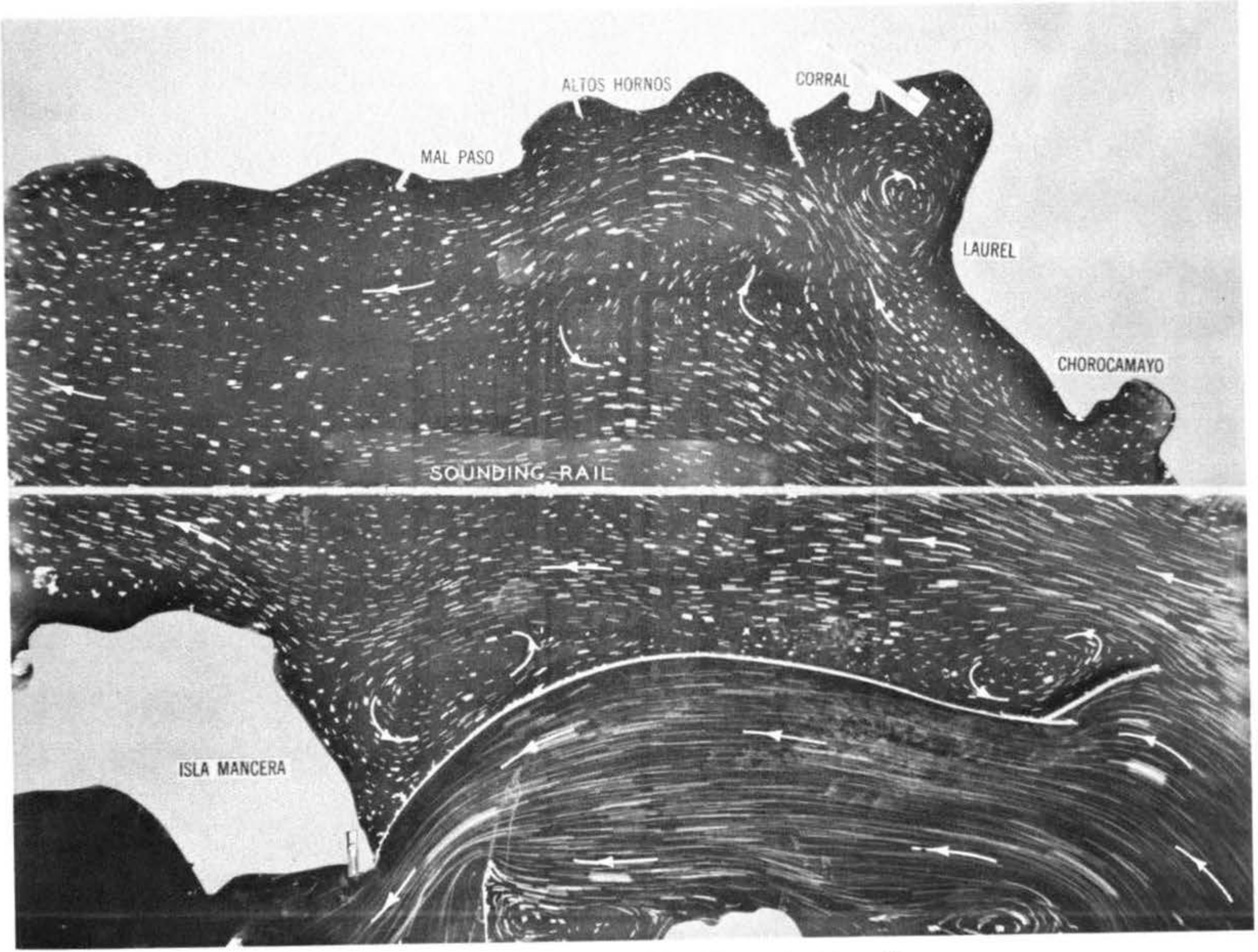
Photograph 10. Strength of ebb, plan 4



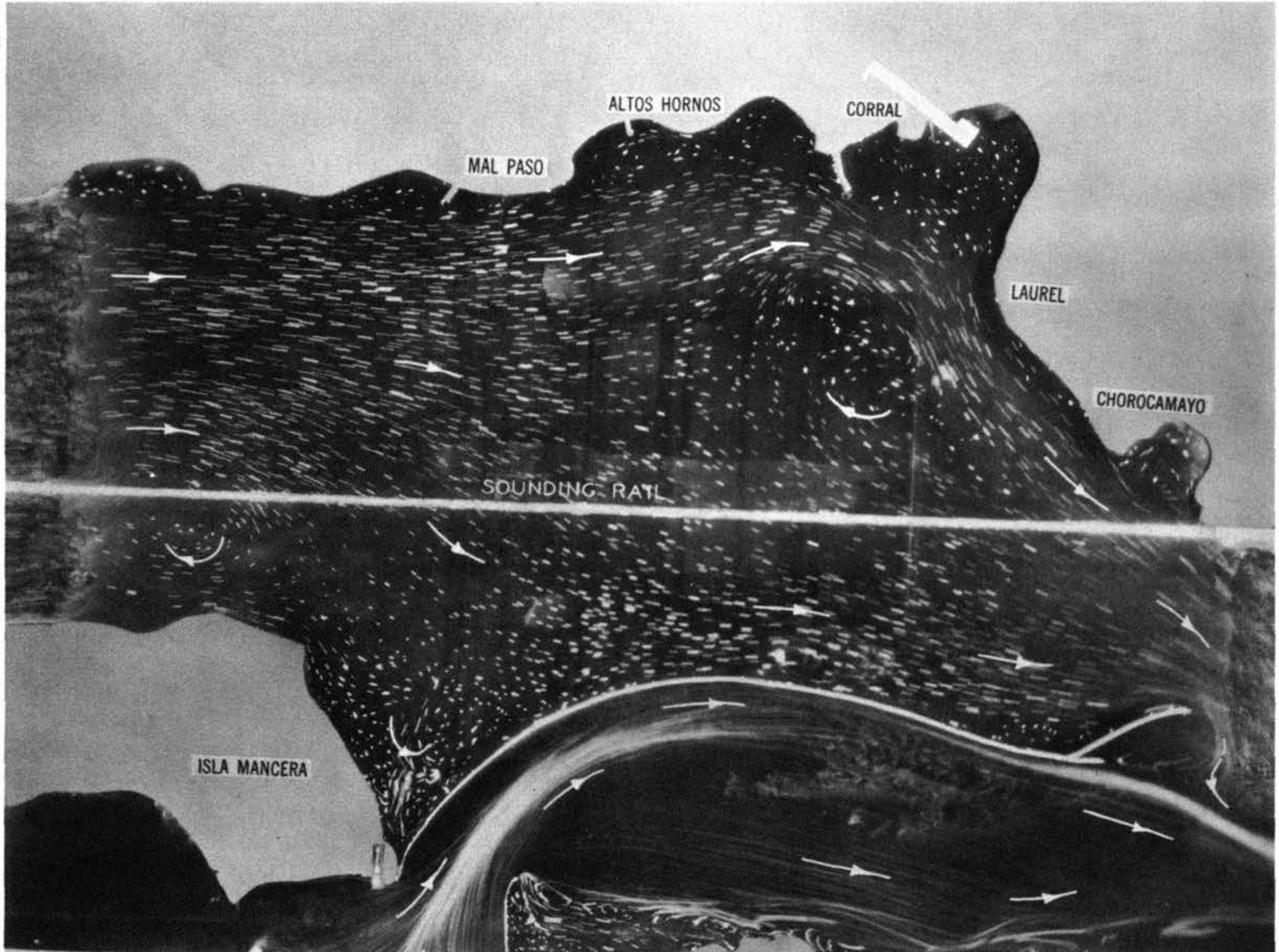
Photograph 11. Strength of flood, plan 5



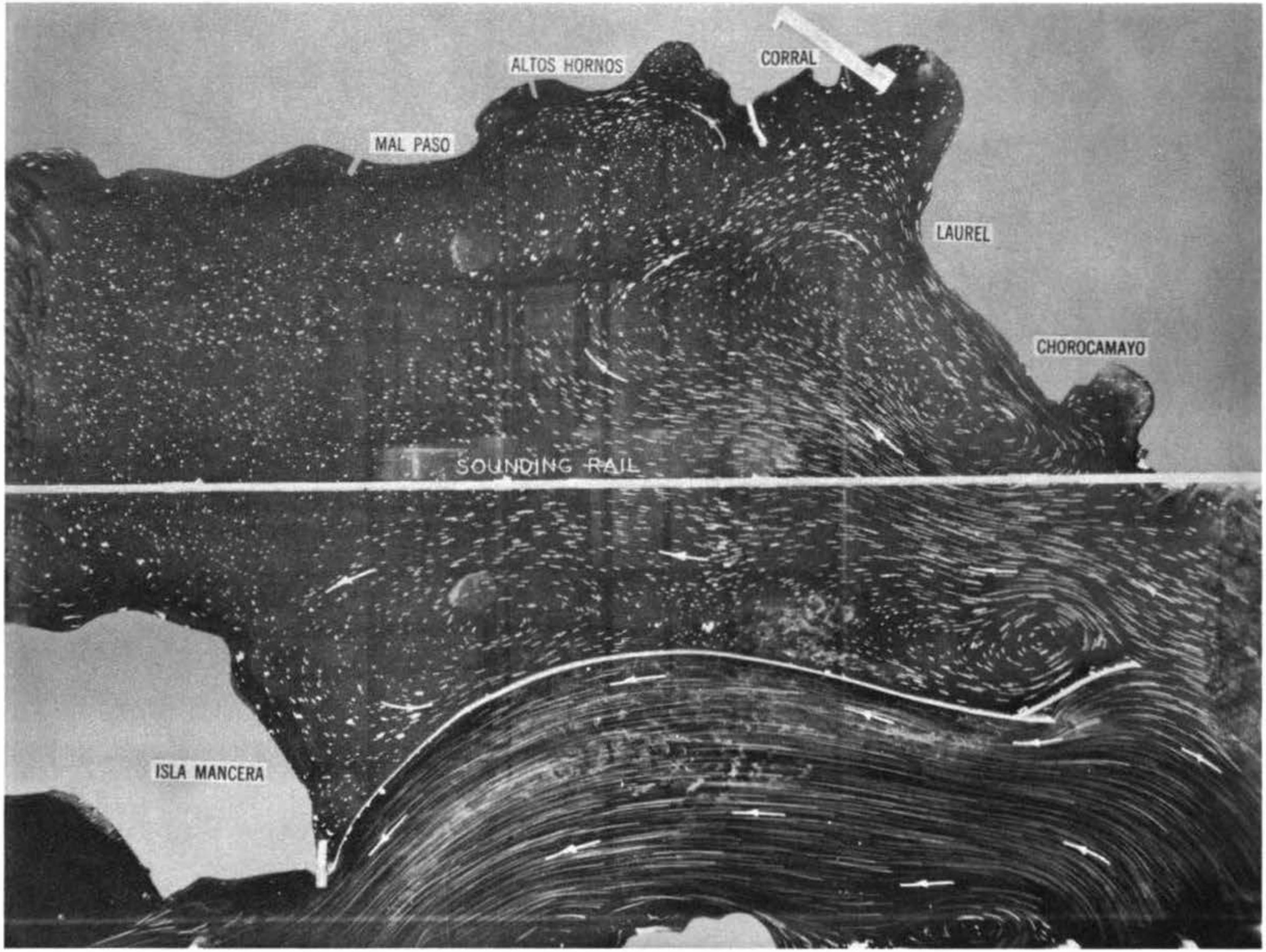
Photograph 12. Strength of ebb, plan 5



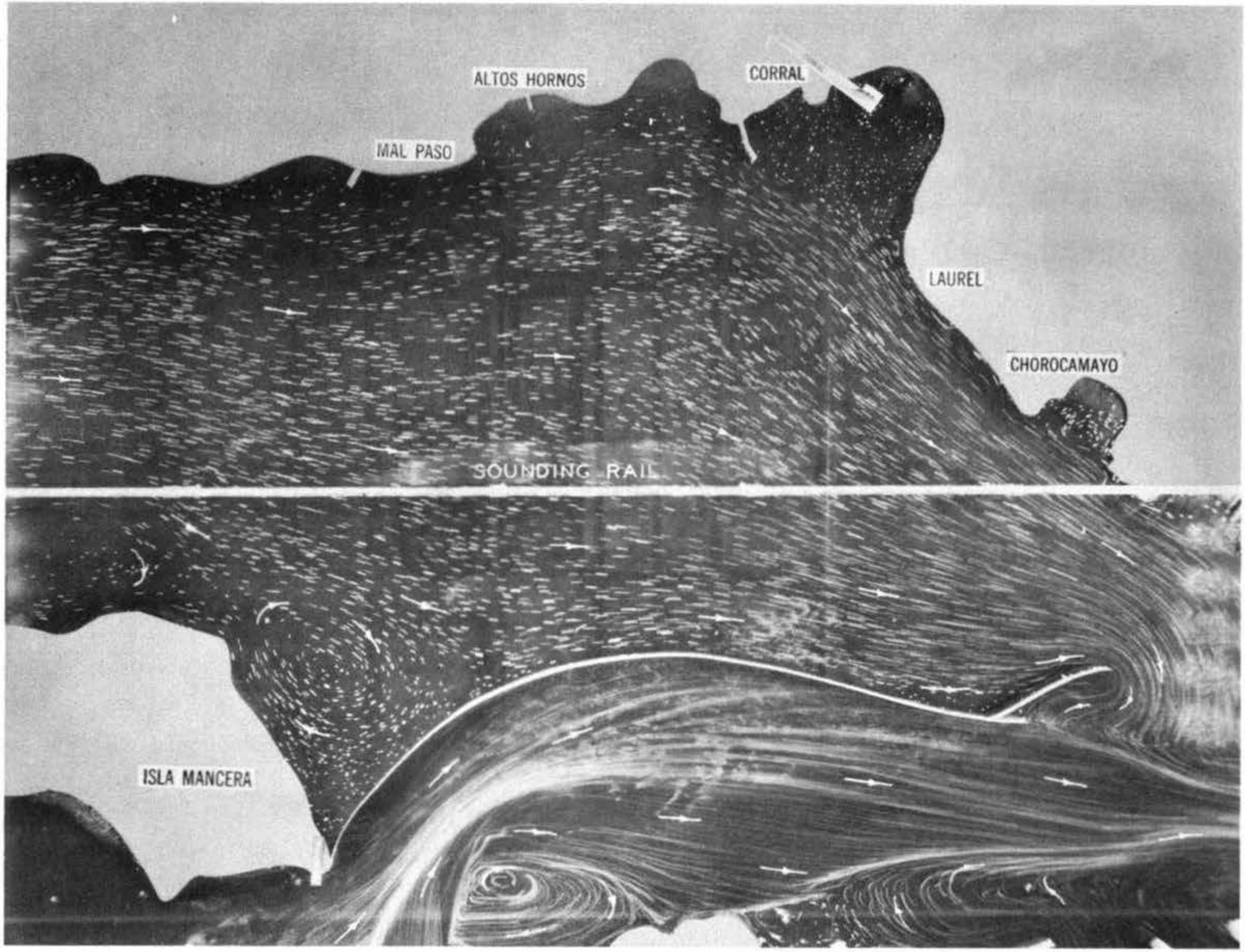
Photograph 13. Strength of flood, plan 6



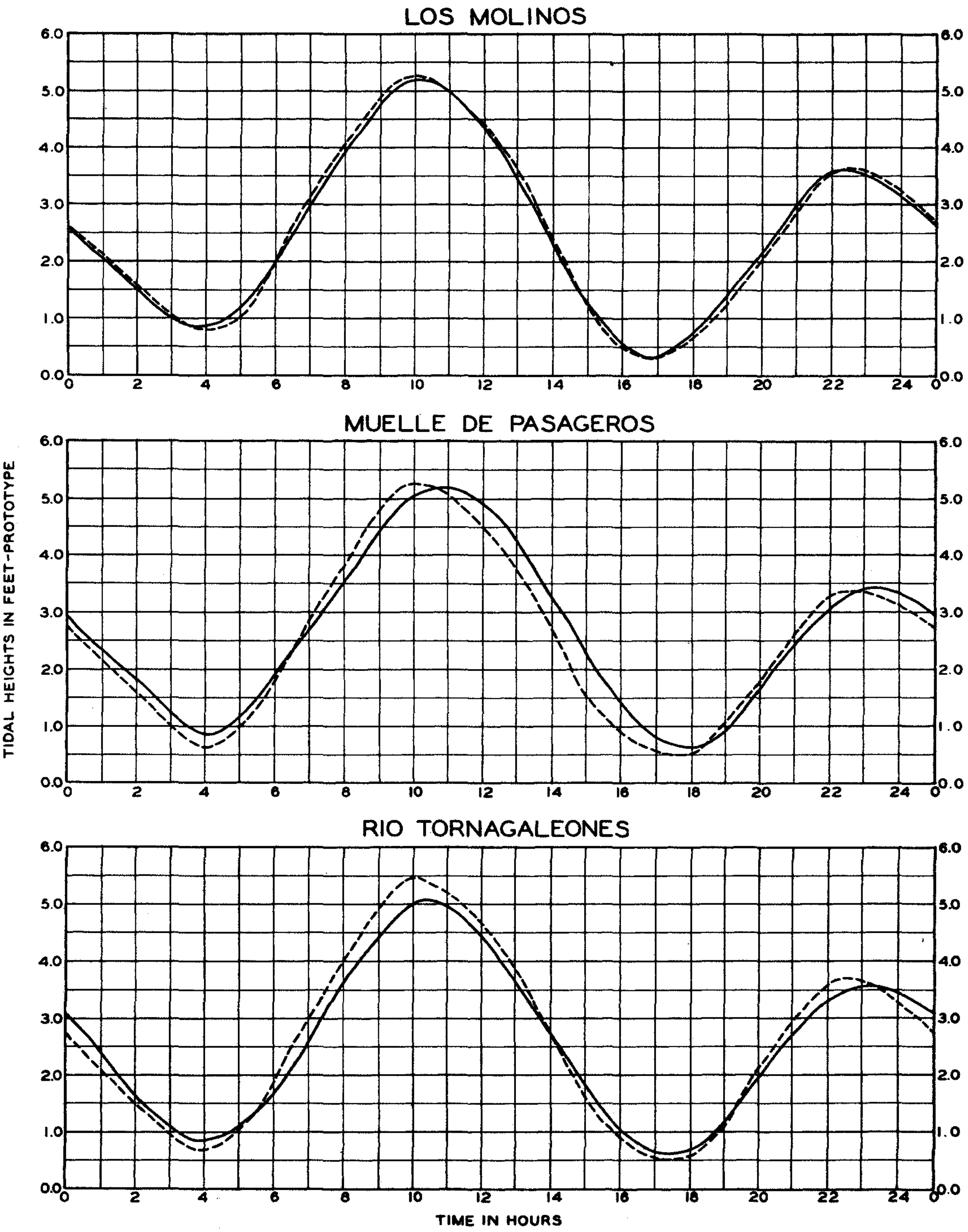
Photograph 14. Strength of ebb, plan 6



Photograph 15. Strength of flood, plan 7



Photograph 16. Strength of ebb, plan 7



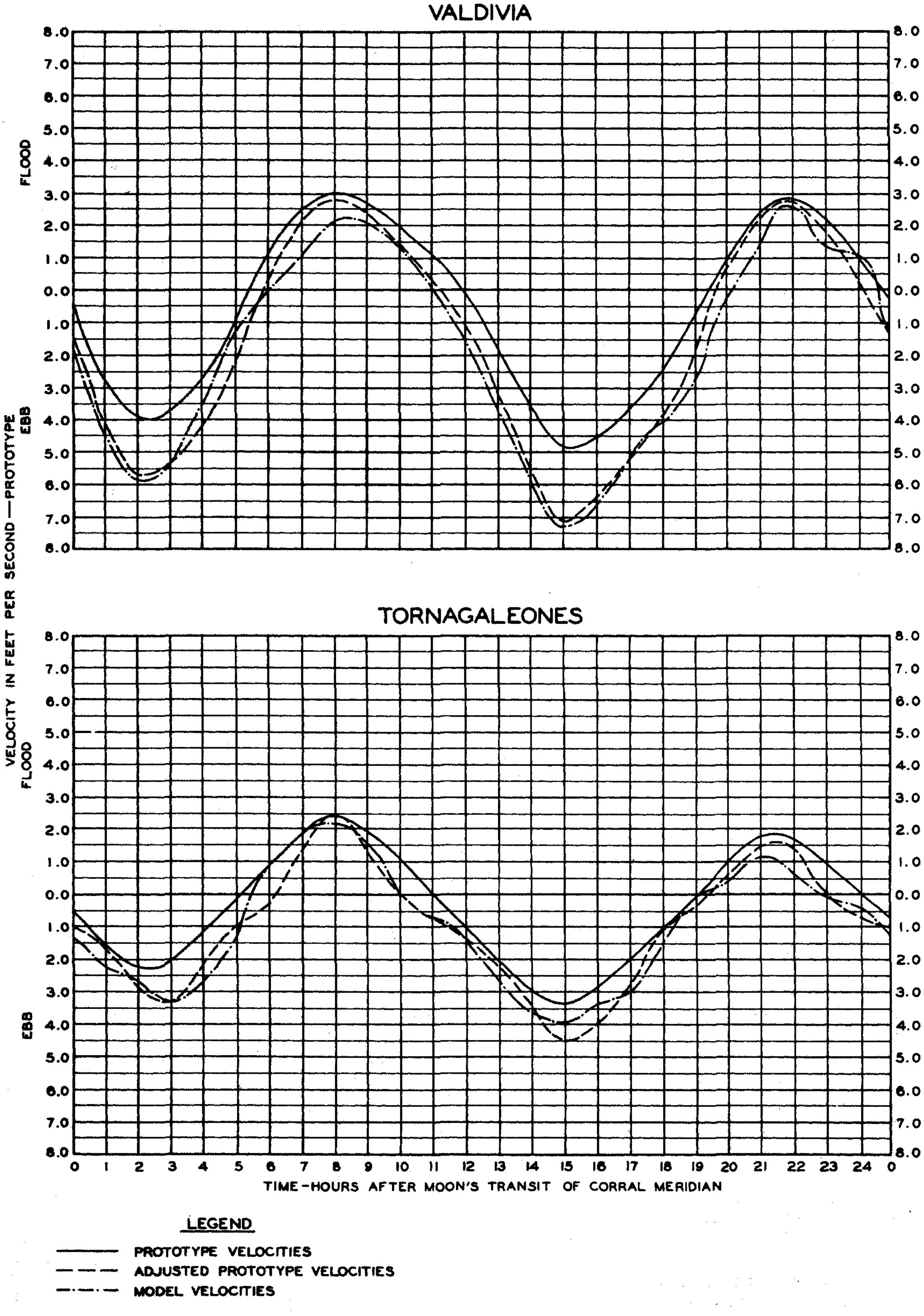
LEGEND

——— BASE TEST TIDAL HEIGHTS
- - - - PLAN TIDAL HEIGHTS

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF CORRAL MERIDIAN.

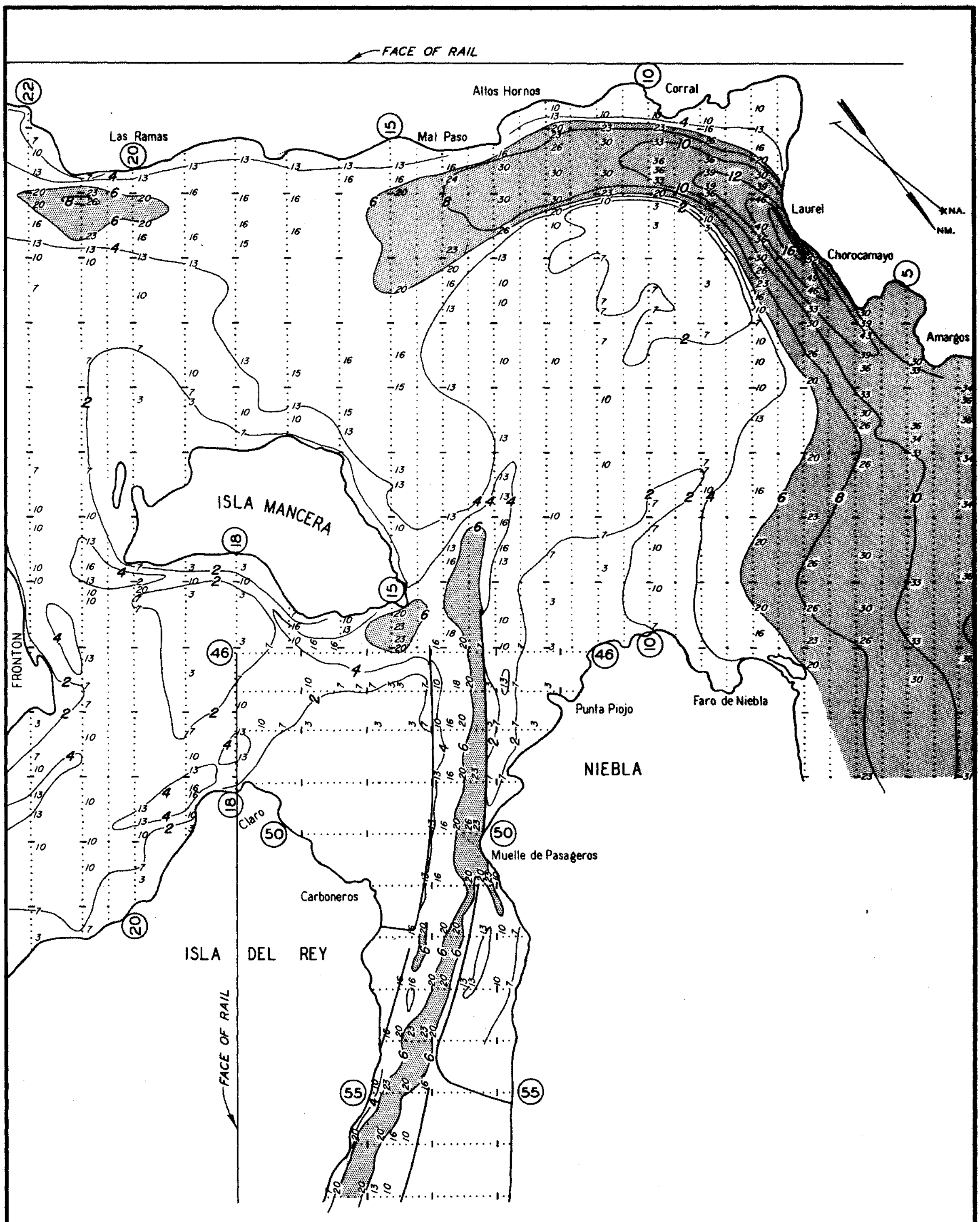
TIDAL HEIGHTS REFERRED TO MEAN LOWER LOW WATER AT LOS MOLINOS.

TIDE CURVES
VERIFICATION TEST



VELOCITY CURVES
VERIFICATION TEST

PLATE 2



LEGEND

—— EXISTING STRUCTURE
– – – PROPOSED STRUCTURE
MORE THAN 6 METERS DEEP MLLW
LESS THAN 6 METERS DEEP MLLW
(15) SOUNDING RANGE

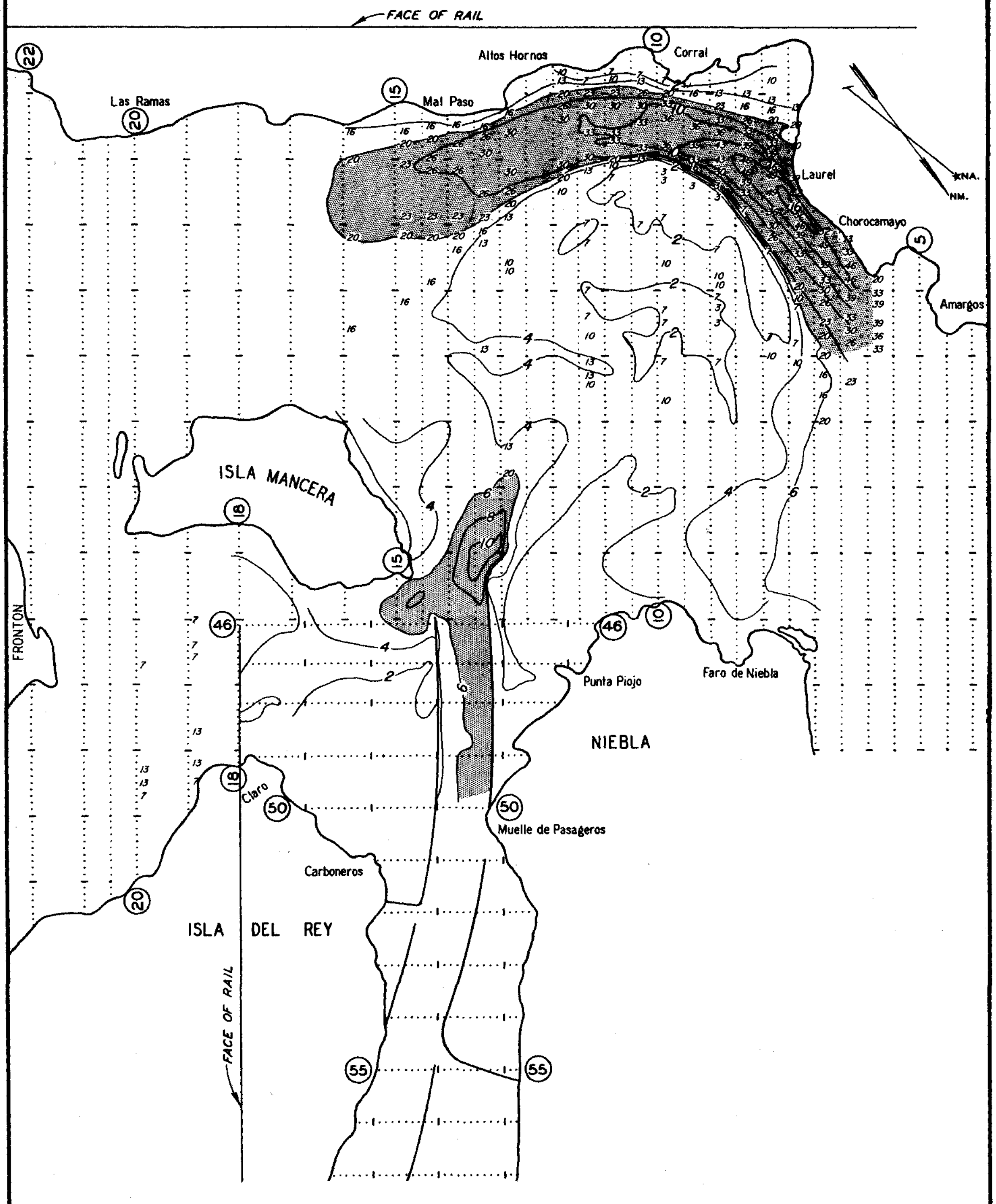
NOTE: SOUNDINGS ARE IN FEET BELOW MEAN LOWER LOW WATER (MLLW). CONTOURS ARE IN METERS BELOW MLLW.

PROTOTYPE SURVEY OF 1946
BEGINNING OF VERIFICATION PERIOD

SCALES

PROTOTYPE 1000 0 1000 2000 FT

MODEL 1 0 1 2 3 4 5 FT



LEGEND

- EXISTING STRUCTURE
- PROPOSED STRUCTURE
- MORE THAN 6 METERS DEEP MLLW
- LESS THAN 6 METERS DEEP MLLW
- (15) SOUNDING RANGE

NOTE: SOUNDINGS ARE IN FEET BELOW MEAN LOWER LOW WATER (MLLW). CONTOURS ARE IN METERS BELOW MLLW.

PROTOTYPE SURVEY OF 1952

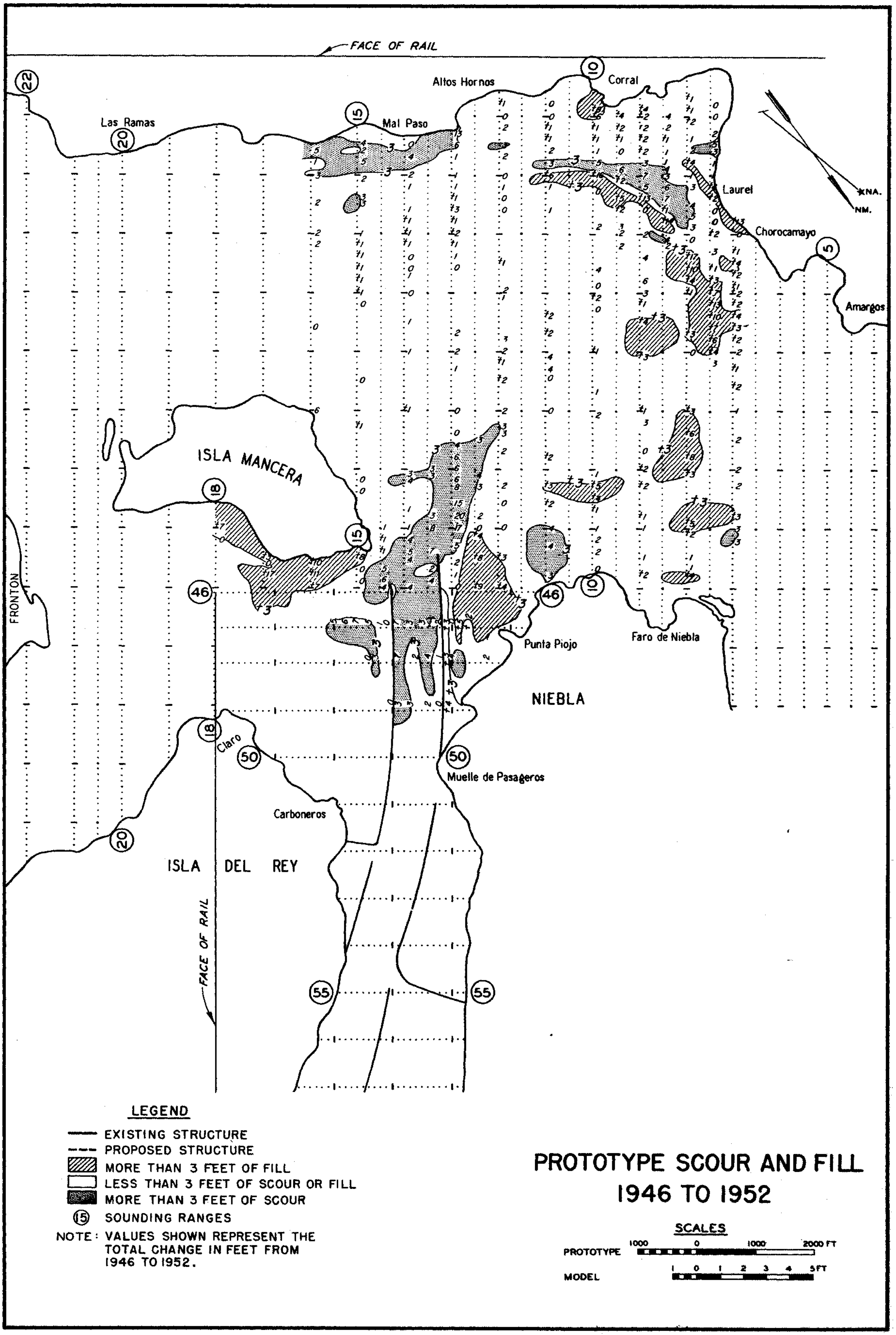
END OF VERIFICATION PERIOD

SCALES

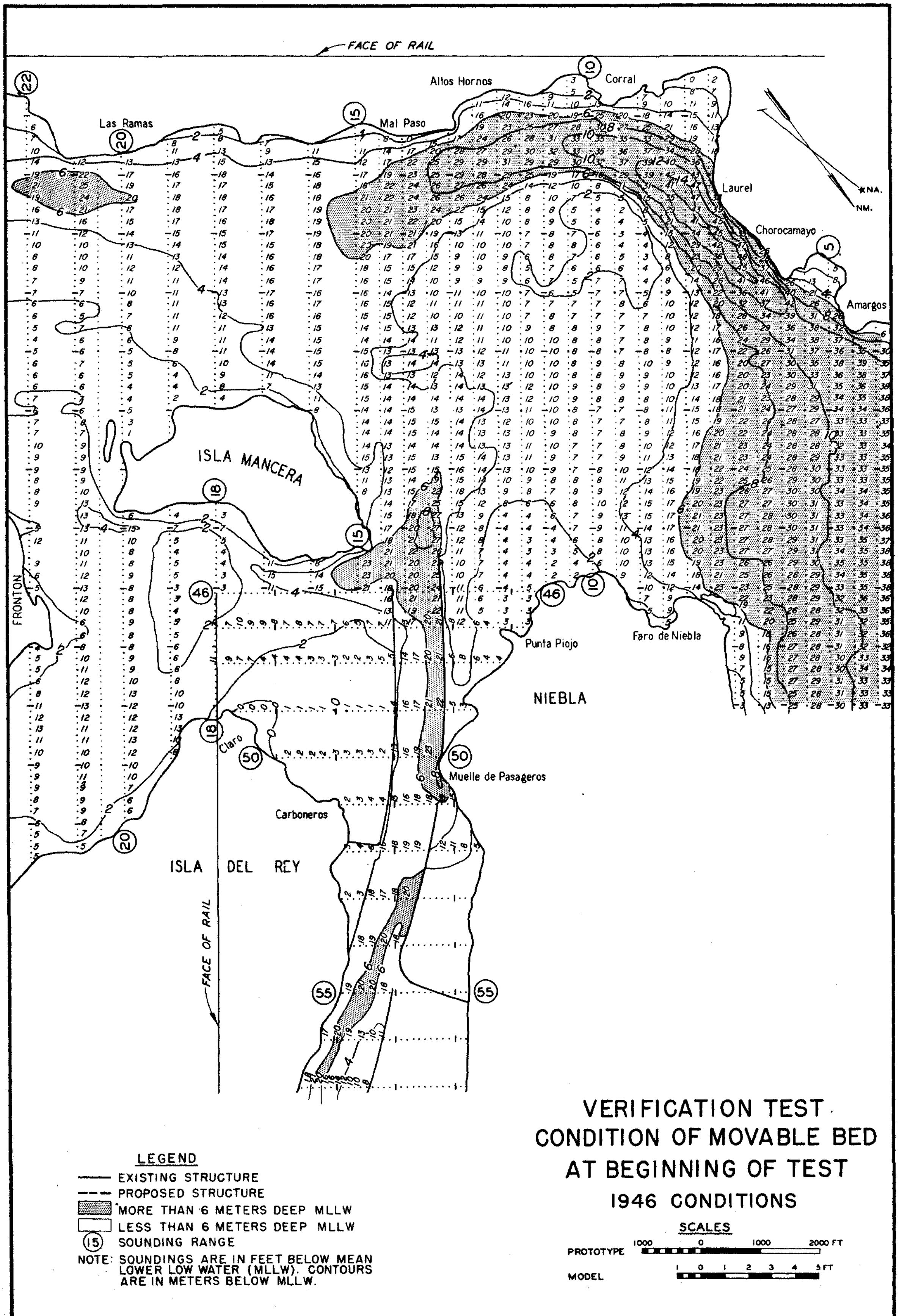
PROTOTYPE 1000 0 1000 2000 FT

MODEL 1 0 1 2 3 4 5 FT

PLATE 4

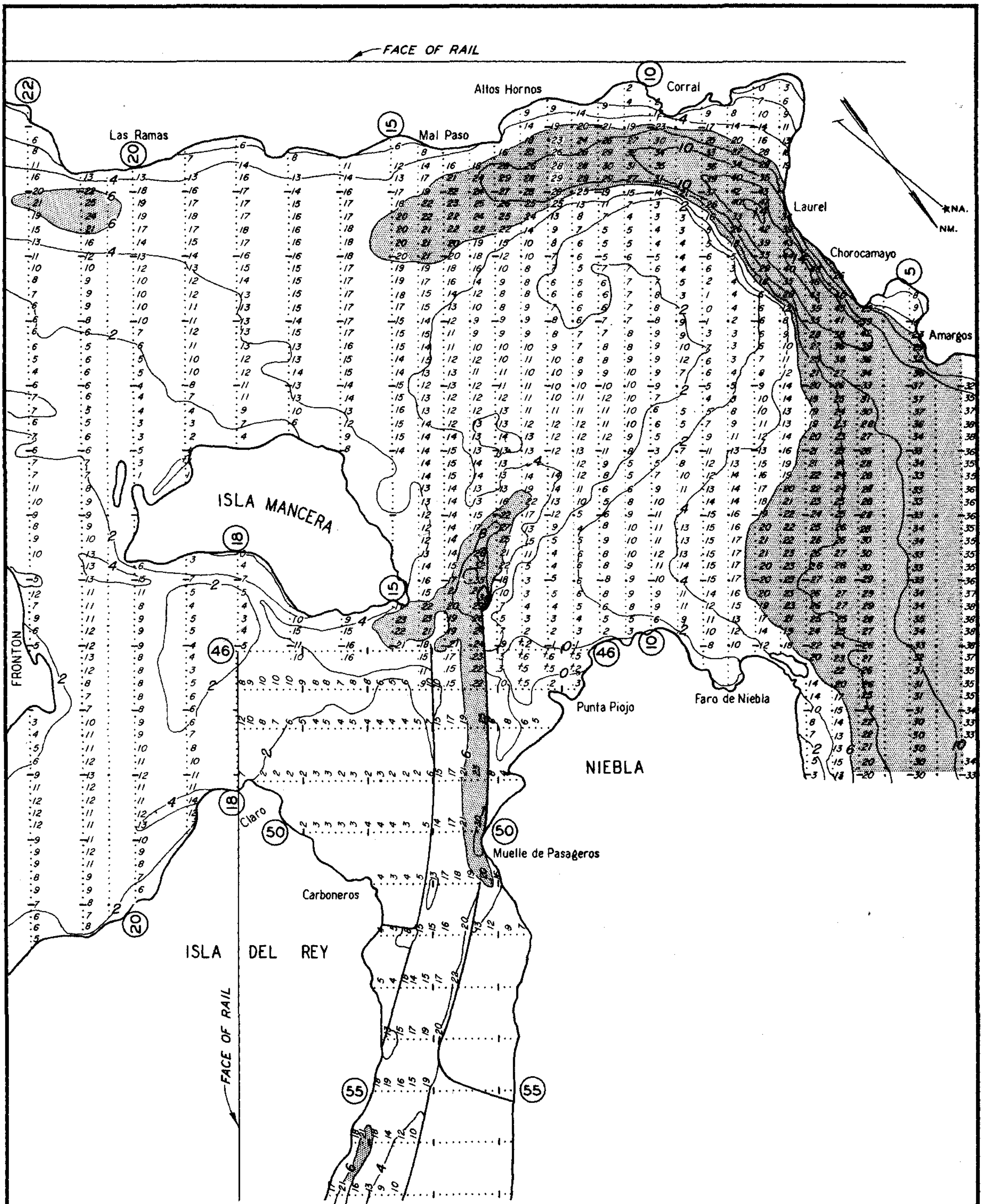


PROTOTYPE SCOUR AND FILL
1946 TO 1952



VERIFICATION TEST
CONDITION OF MOVABLE BED
AT BEGINNING OF TEST
1946 CONDITIONS

PLATE 6



LEGEND

—— EXISTING STRUCTURE
– – – PROPOSED STRUCTURE
MORE THAN 6 METERS DEEP MLLW
LESS THAN 6 METERS DEEP MLLW
(15) SOUNDING RANGE

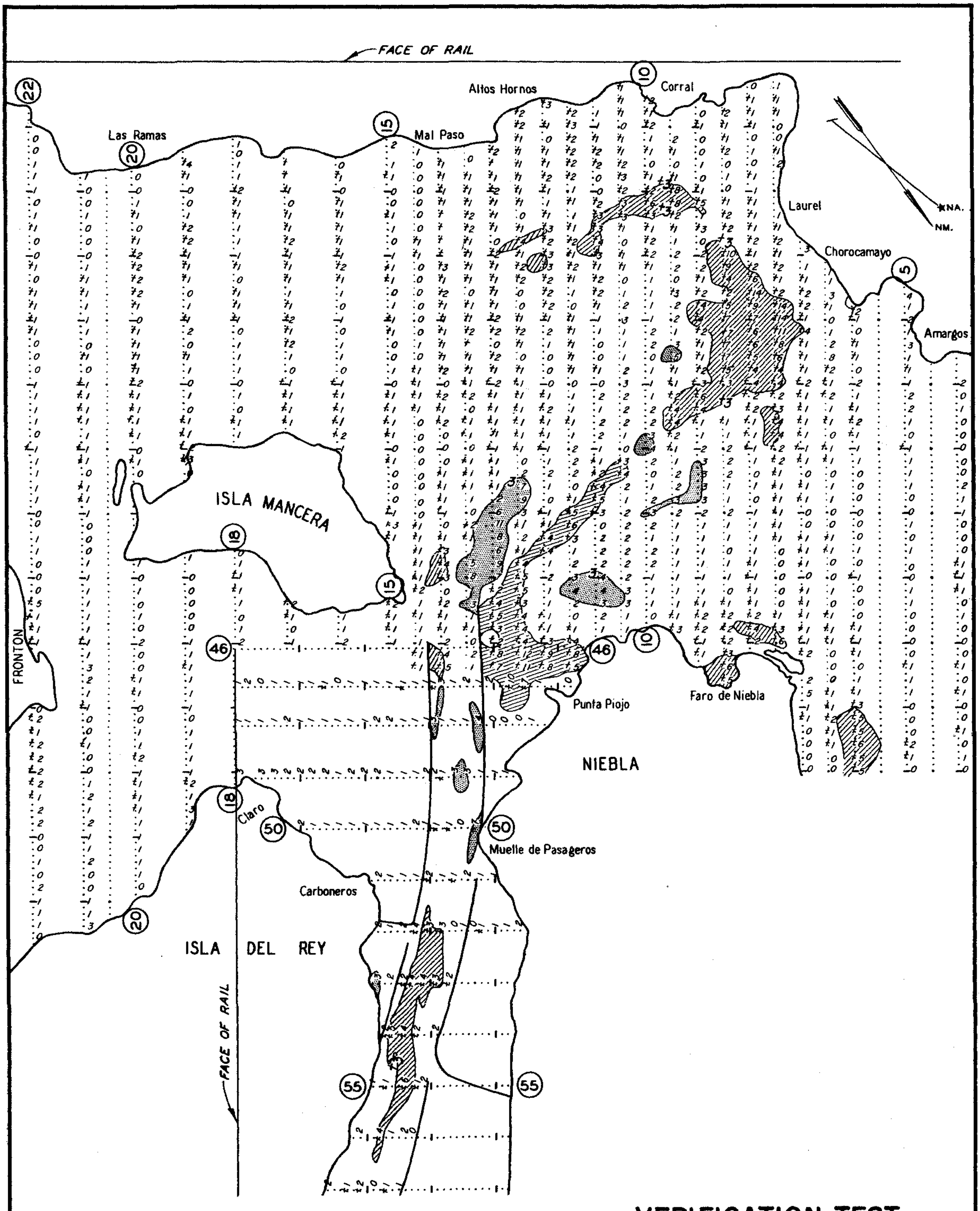
NOTE: SOUNDINGS ARE IN FEET BELOW MEAN LOWER LOW WATER (MLLW). CONTOURS ARE IN METERS BELOW MLLW.

VERIFICATION TEST
CONDITION OF MOVABLE BED
AT END OF 6 YEARS
(36 TIDAL CYCLES)

SCALES

PROTOTYPE 1000 0 1000 2000 FT

MODEL 1 0 1 2 3 4 5 FT



VERIFICATION TEST SCOUR AND FILL DURING 6 YEAR PERIOD (36 TIDAL CYCLES)

LEGEND

- EXISTING STRUCTURE
- PROPOSED STRUCTURE
- MORE THAN 3 FEET OF FILL
- LESS THAN 3 FEET OF SCOUR OR FILL
- MORE THAN 3 FEET OF SCOUR
- (15) SOUNDING RANGE

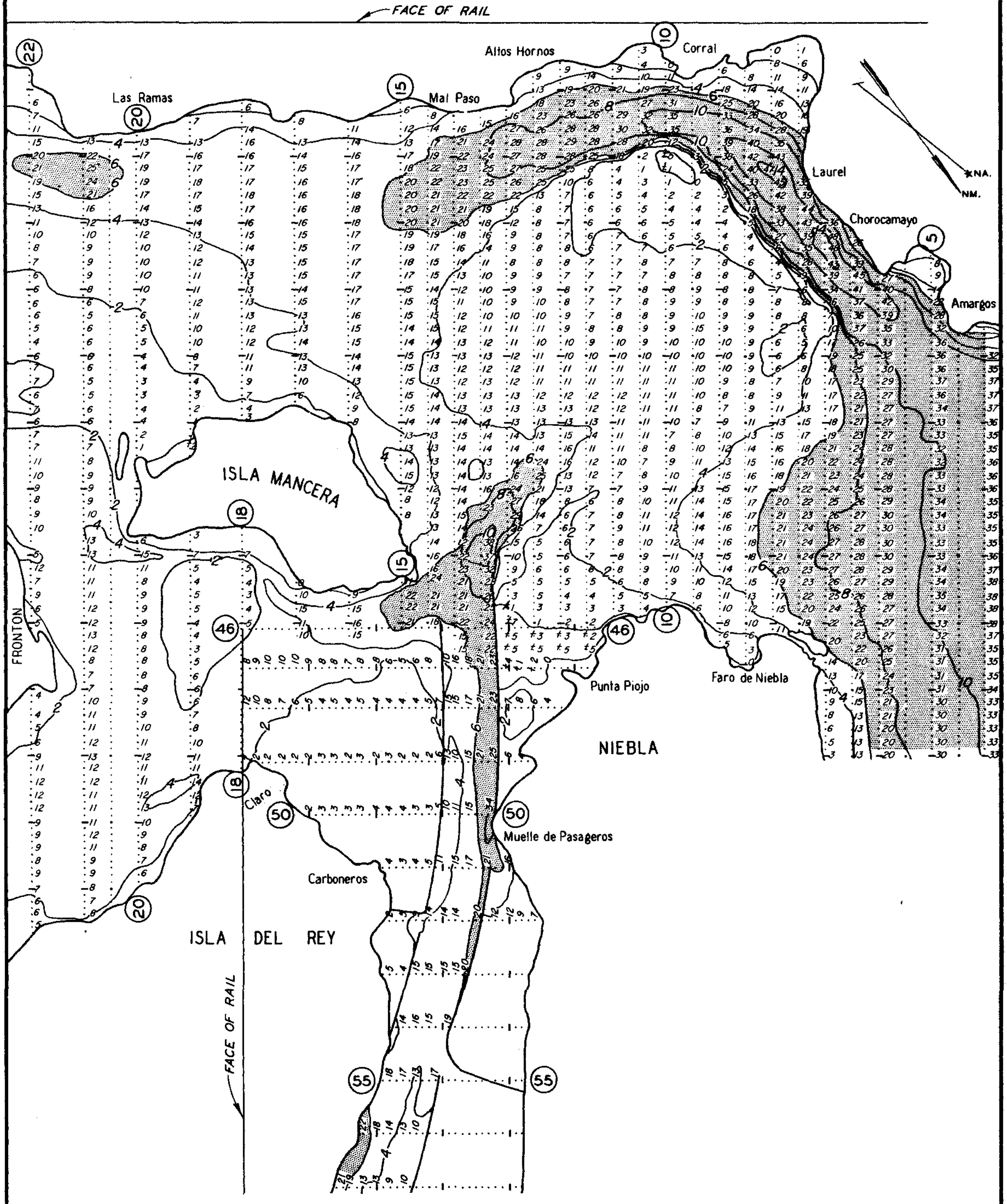
NOTE: VALUES SHOWN REPRESENT THE TOTAL CHANGE IN FEET FROM START TO END OF TEST.

SCALES

PROTOTYPE 1000 0 1000 2000 FT

MODEL 1 0 1 2 3 4 5 FT

PLATE 8



BASE TEST

CONDITION OF MOVABLE BED AT END OF 12 YEARS

LEGEND

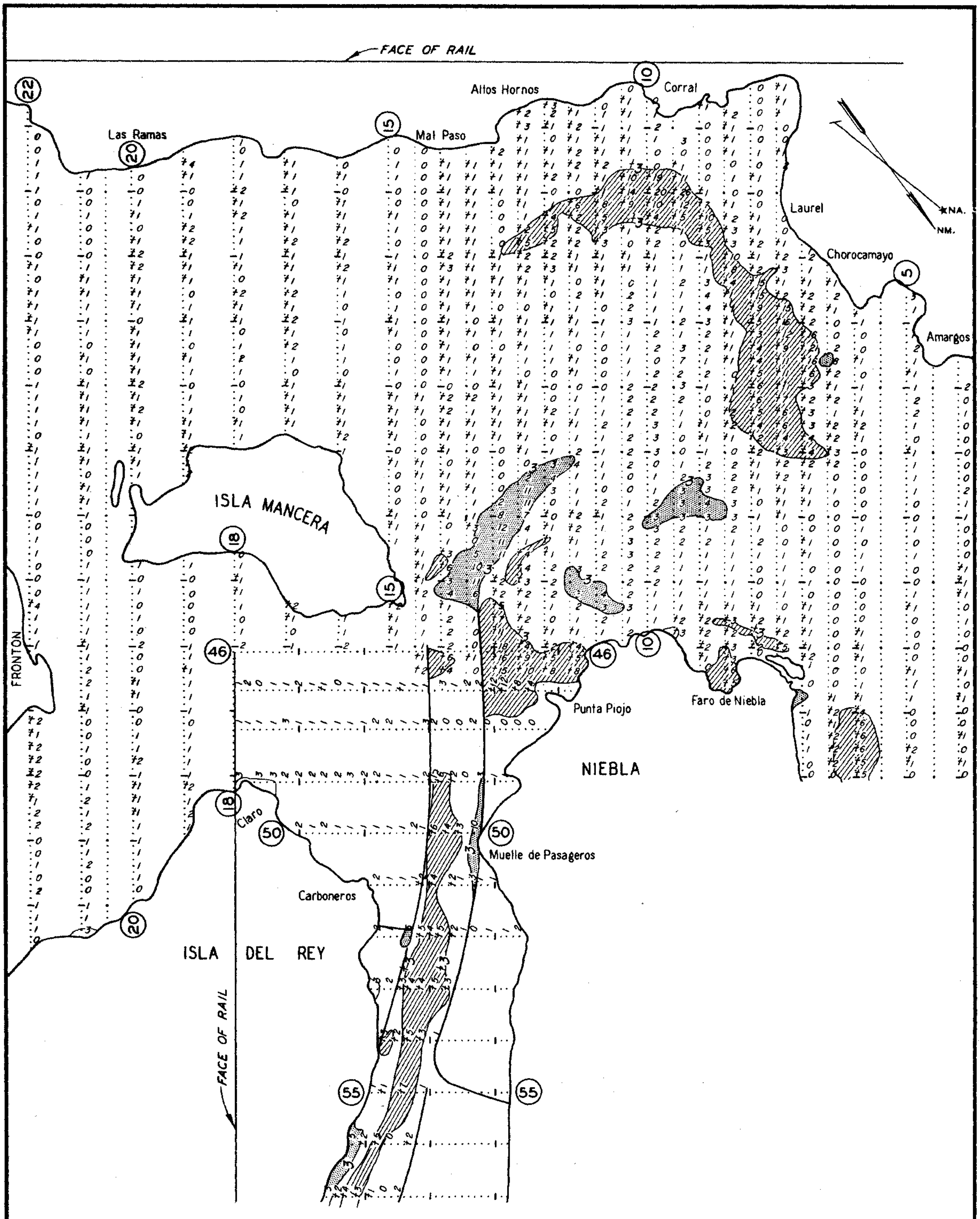
- EXISTING STRUCTURE
- PROPOSED STRUCTURE
- MORE THAN 6 METERS DEEP MLLW
- LESS THAN 6 METERS DEEP MLLW
- (15) SOUNDING RANGE

NOTE: SOUNDINGS ARE IN FEET BELOW MEAN LOWER LOW WATER (MLLW). CONTOURS ARE IN METERS BELOW MLLW.

SCALES

PROTOTYPE 1000 0 1000 2000 FT

MODEL 1 0 1 2 3 4 5 FT



LEGEND

EXISTING STRUCTURE
PROPOSED STRUCTURE
MORE THAN 3 FEET OF FILL
LESS THAN 3 FEET OF SCOUR OR FILL
MORE THAN 3 FEET OF SCOUR
(15) SOUNDING RANGE

NOTE: VALUES SHOWN REPRESENT THE TOTAL CHANGE IN FEET FROM START TO END OF TEST.

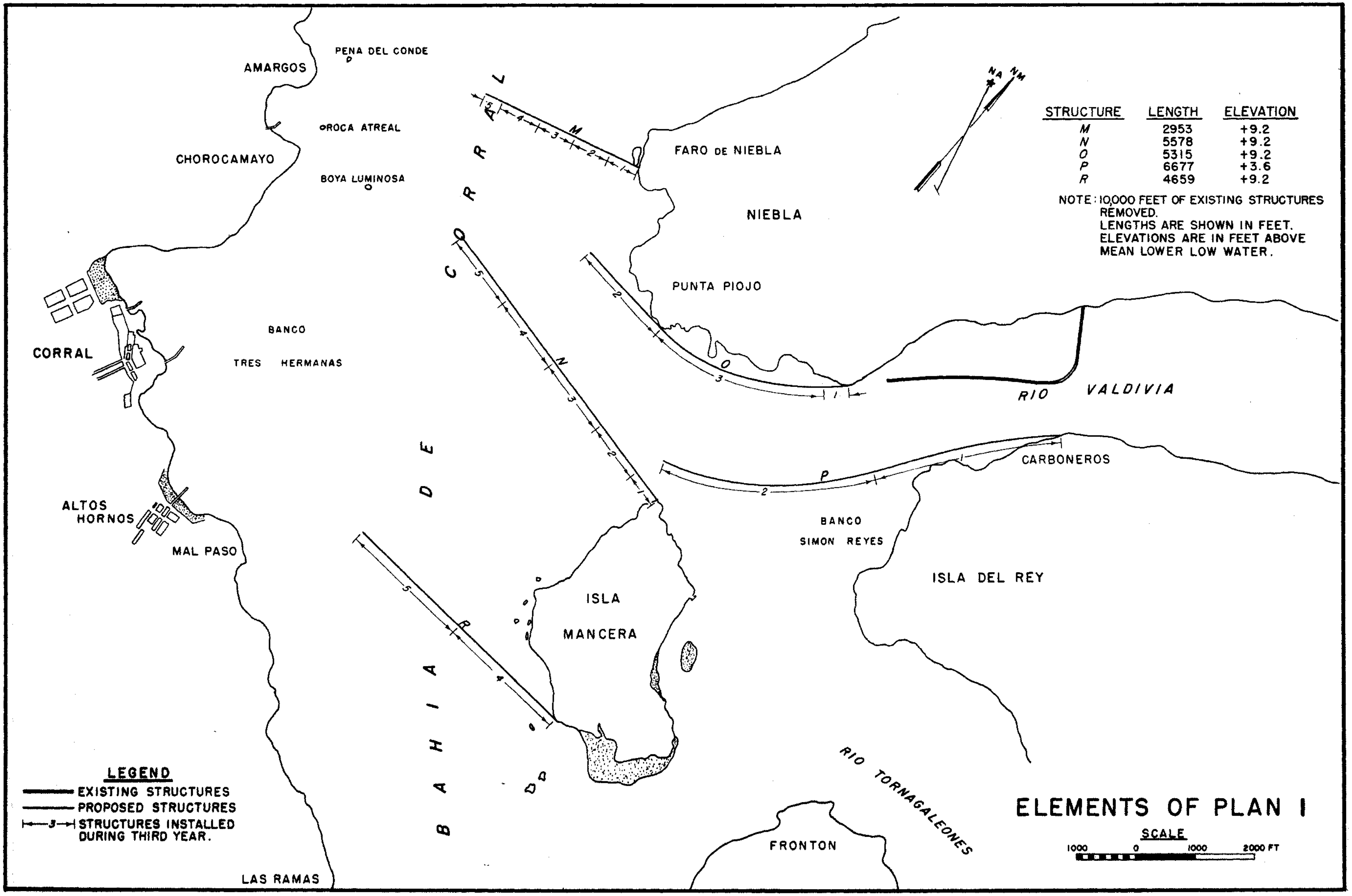
BASE TEST SCOUR AND FILL DURING 12 YEAR PERIOD

SCALES

PROTOTYPE 1000 0 1000 2000 FT

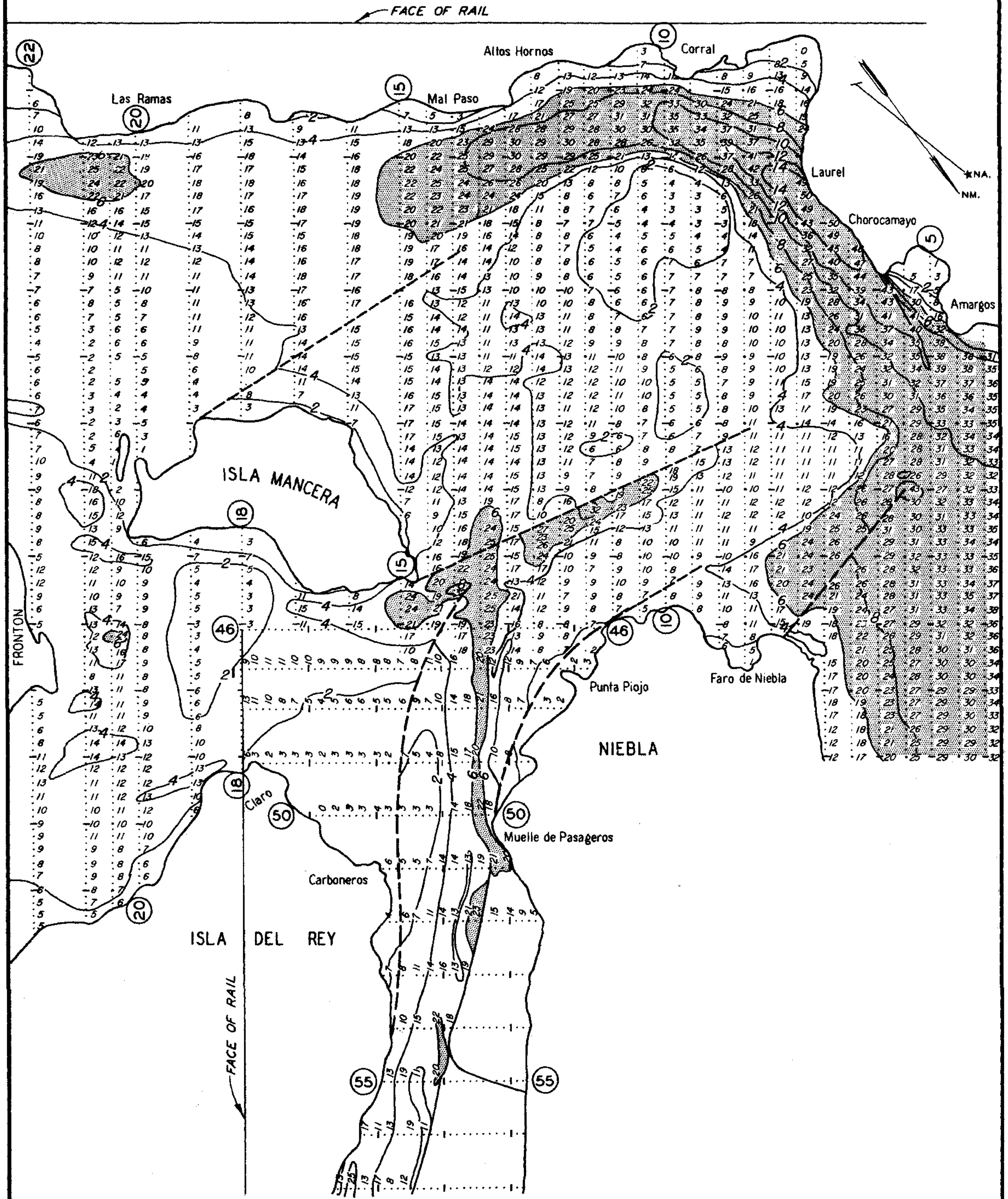
MODEL 1 0 1 2 3 4 5 FT

PLATE 10



ELEMENTS OF PLAN I

PLATE 11



LEGEND

—— EXISTING STRUCTURE

– – – PROPOSED STRUCTURE

MORE THAN 6 METERS DEEP MLLW

LESS THAN 6 METERS DEEP MLLW

(15) SOUNDING RANGE

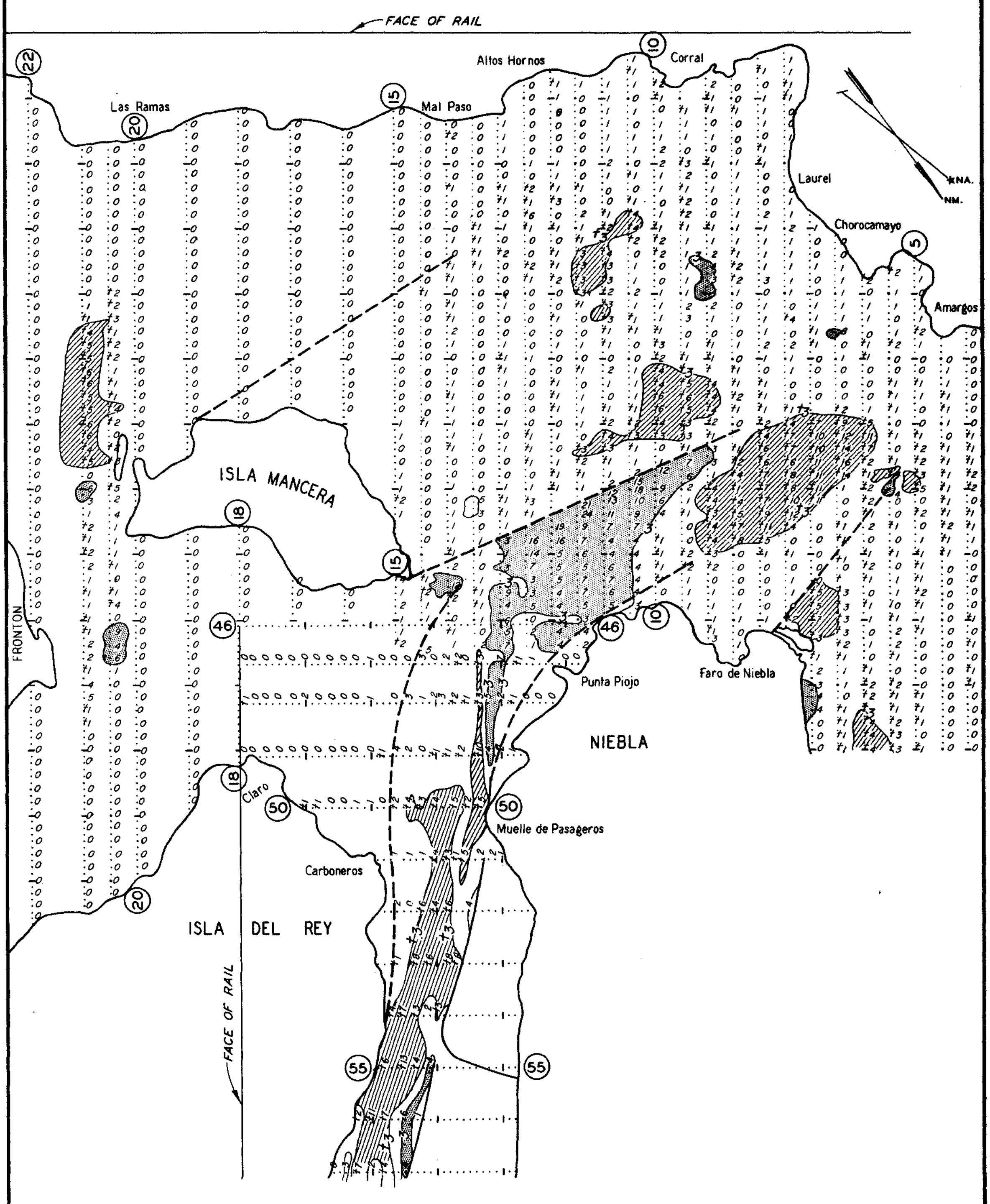
NOTE: SOUNDINGS ARE IN FEET BELOW MEAN LOWER LOW WATER (MLLW). CONTOURS ARE IN METERS BELOW MLLW.

PLAN 1
CONDITION OF MOVABLE BED AT END OF TEST
DURATION OF TEST 12 YEARS

SCALES

PROTOTYPE 1000 0 1000 2000 FT

MODEL 1 0 1 2 3 4 5 FT



LEGEND

- EXISTING STRUCTURE
- PROPOSED STRUCTURE
- MORE THAN 3 FEET OF FILL
- LESS THAN 3 FEET OF SCOUR OR FILL
- MORE THAN 3 FEET OF FILL
- (15) SOUNDING RANGE

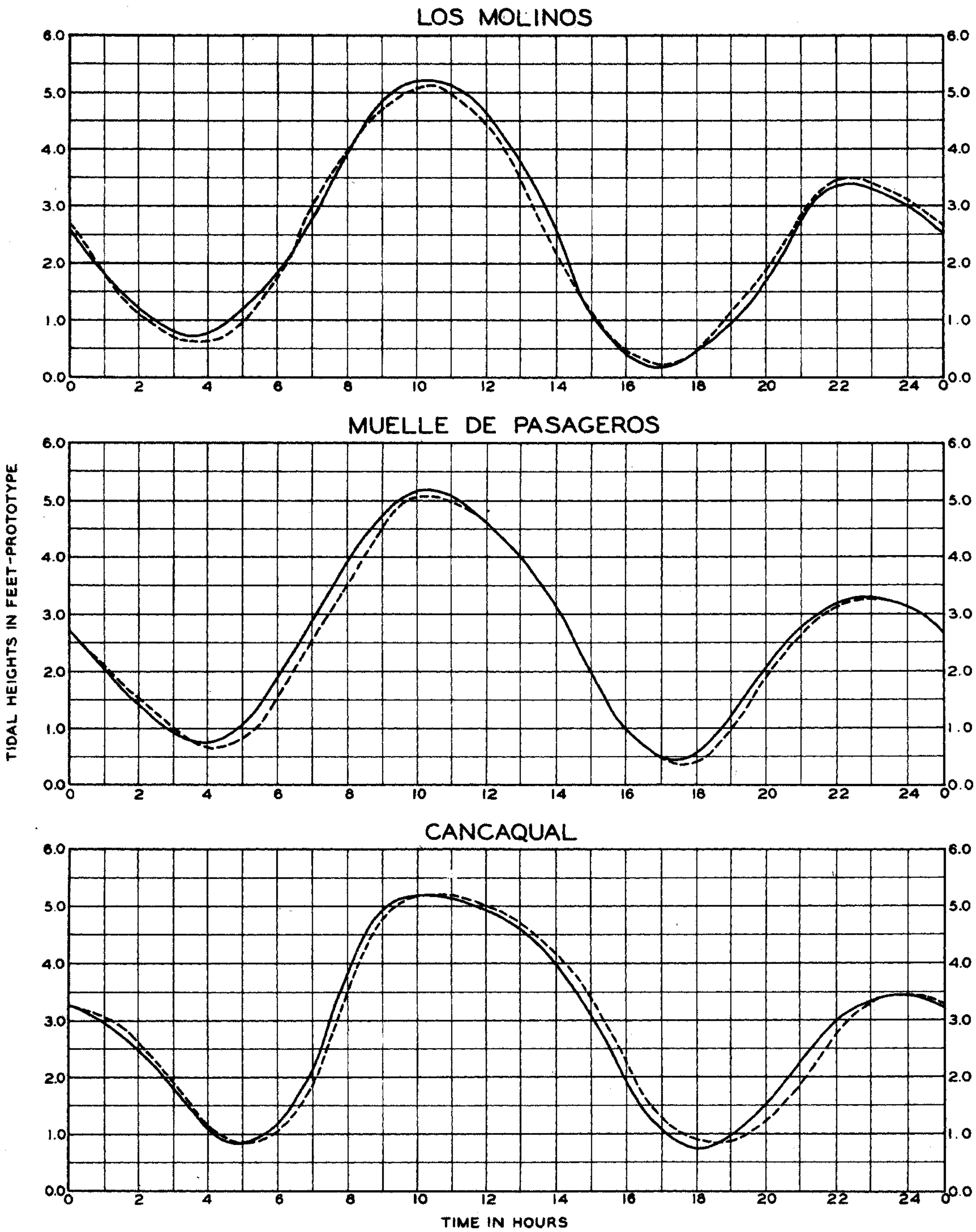
NOTE: VALUES SHOWN REPRESENT THE TOTAL CHANGE IN FEET FROM START TO END OF TEST.

PLAN I
SCOUR AND FILL DURING TEST

SCALES

PROTOTYPE 1000 0 1000 2000 FT

MODEL 1 0 1 2 3 4 5 FT



LEGEND

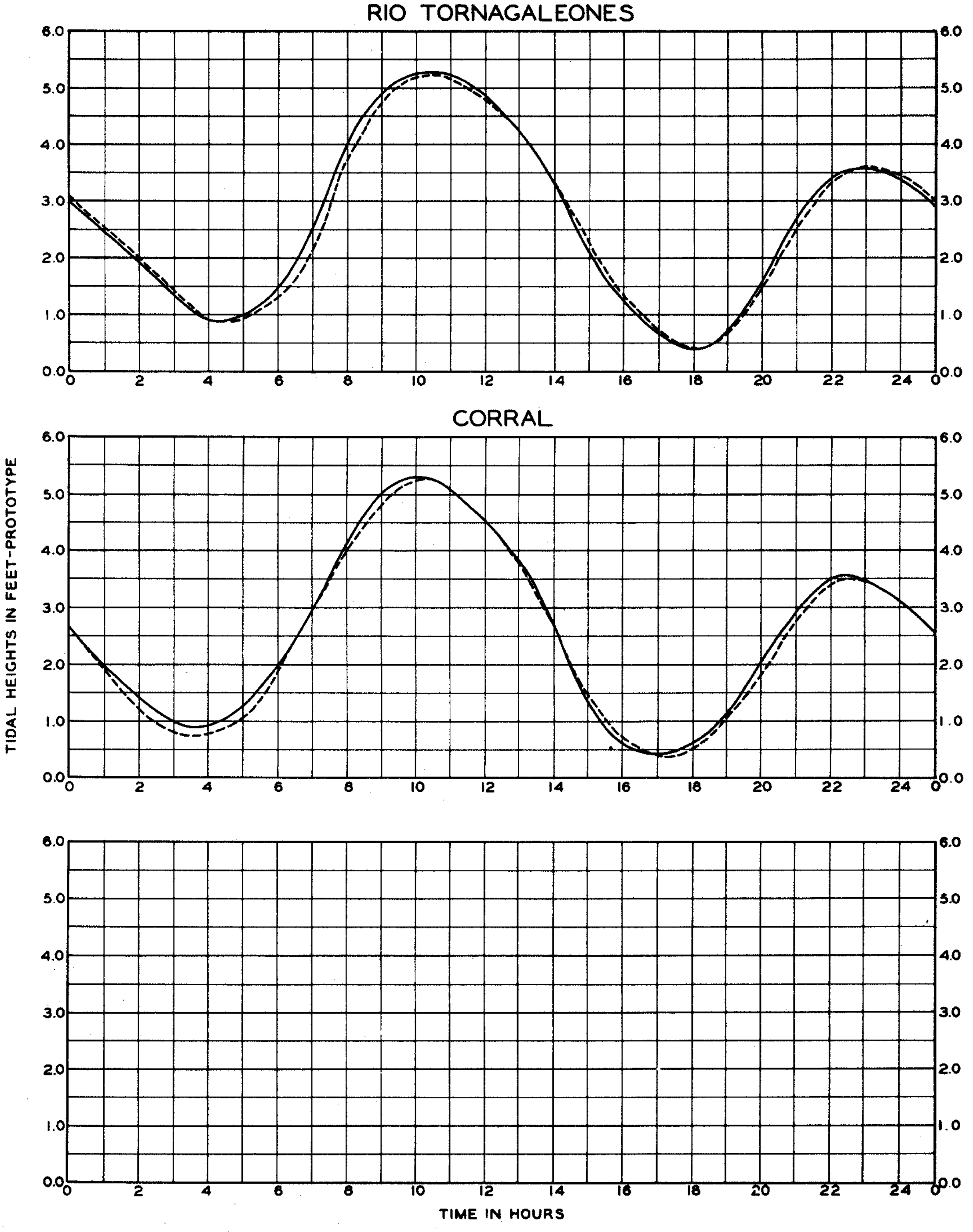
——— BASE TEST TIDAL HEIGHTS

- - - - - PLAN TIDAL HEIGHTS

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF CORRAL MERIDIAN.

TIDAL HEIGHTS REFERRED TO MEAN LOWER LOW WATER AT LOS MOLINOS.

TIDE CURVES
PLAN I
LOS MOLINOS, MUELLE DE PASAGEROS
AND CANCAQUAL



LEGEND

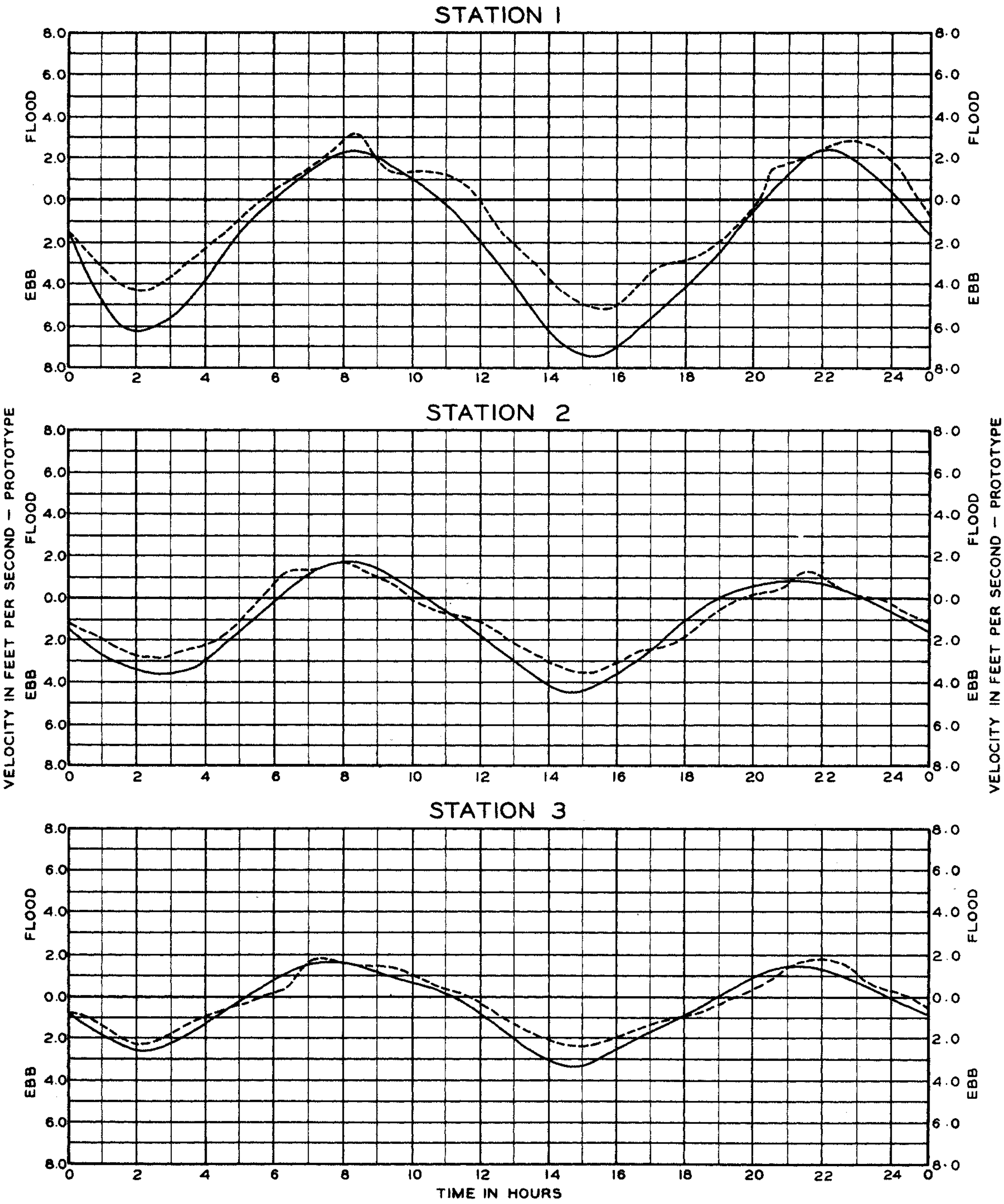
——— BASE TEST TIDAL HEIGHTS

- - - - PLAN TIDAL HEIGHTS

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF CORRAL MERIDIAN.

TIDAL HEIGHTS REFERRED TO MEAN LOWER LOW WATER AT LOS MOLINOS.

TIDE CURVES
PLAN I
RIO TORNAGALEONES AND CORRAL

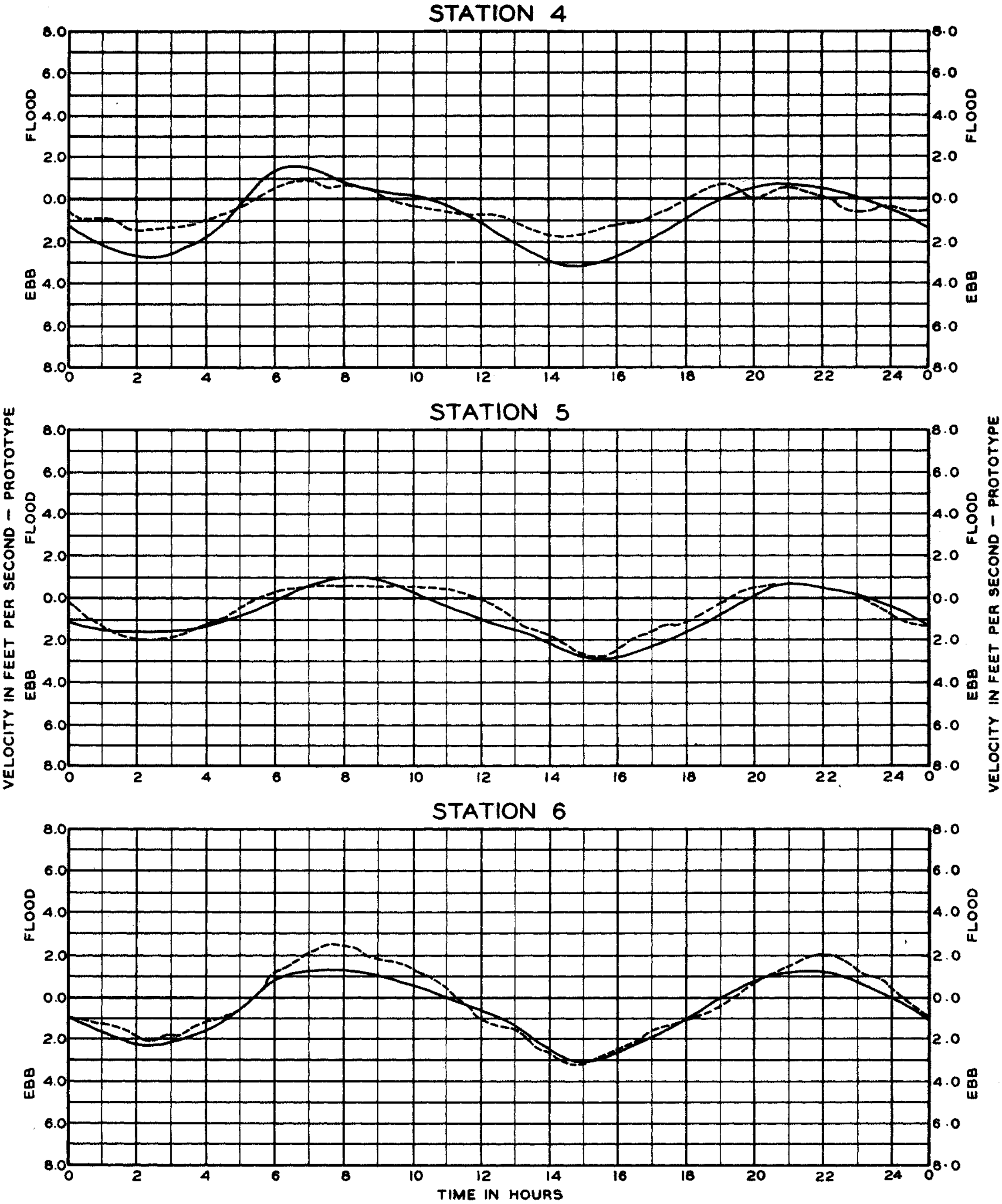


LEGEND

——— BASE TEST VELOCITY CURVES
------ PLAN VELOCITY CURVES

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF CORRAL MERIDIAN.

VELOCITY CURVES
PLAN 1
STATIONS 1 TO 3



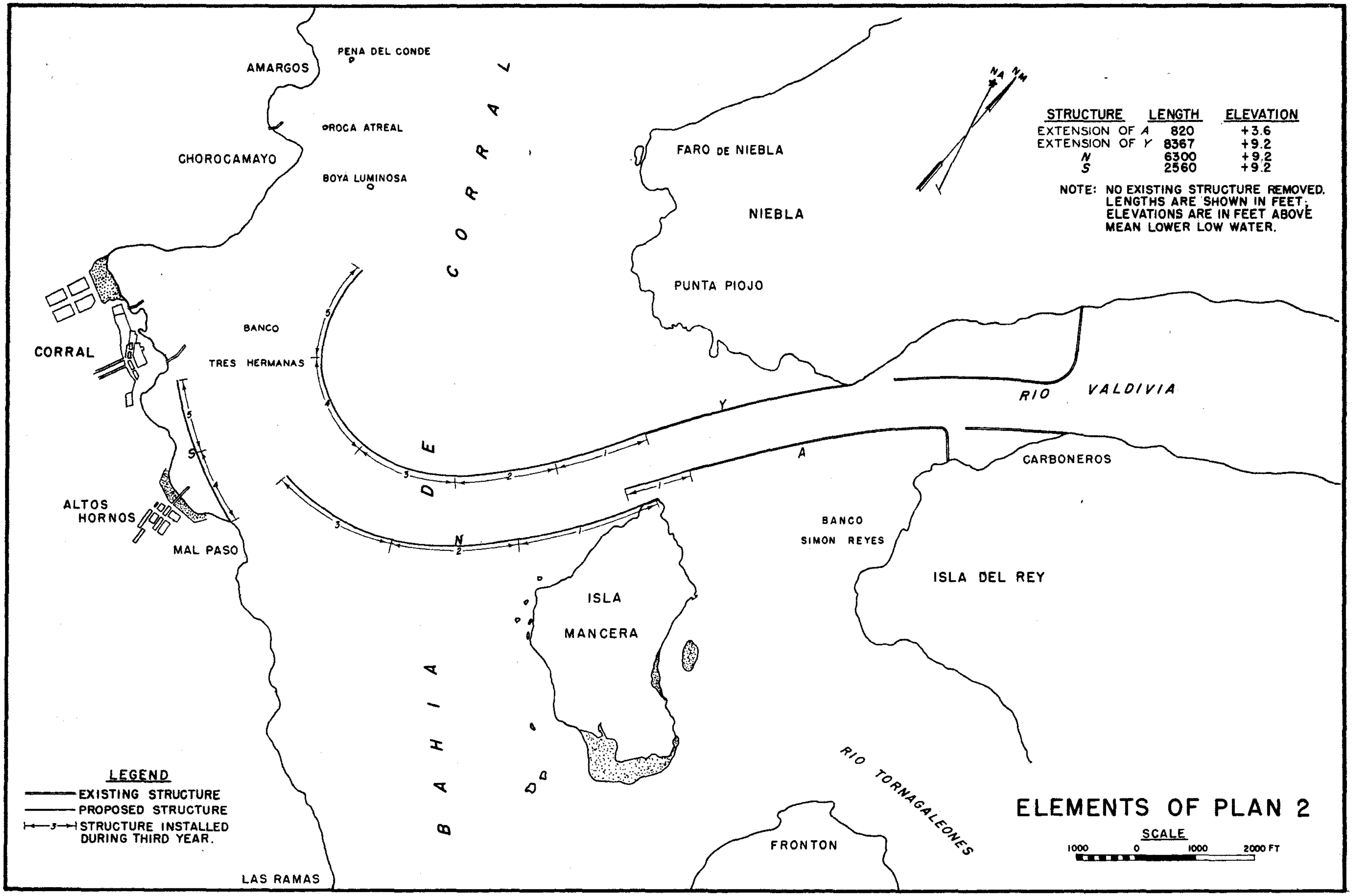
LEGEND

——— BASE TEST VELOCITY CURVES
------ PLAN VELOCITY CURVES

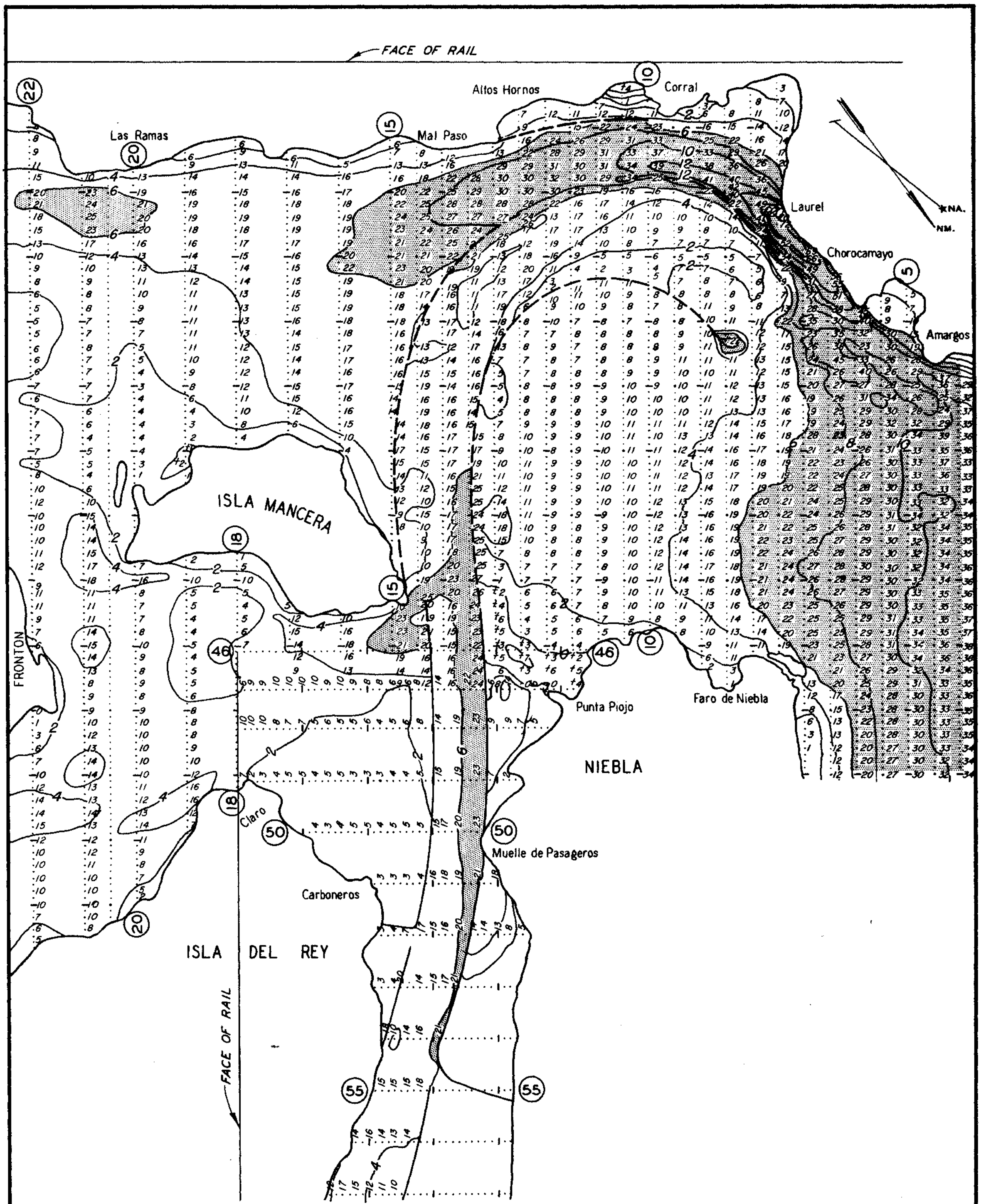
NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF CORRAL MERIDIAN.

VELOCITY CURVES
PLAN I
STATIONS 4 TO 6

PLATE 18



ELEMENTS OF PLAN 2



LEGEND

—— EXISTING STRUCTURE

– – – PROPOSED STRUCTURE

MORE THAN 6 METERS DEEP MLLW

LESS THAN 6 METERS DEEP MLLW

(15) SOUNDING RANGE

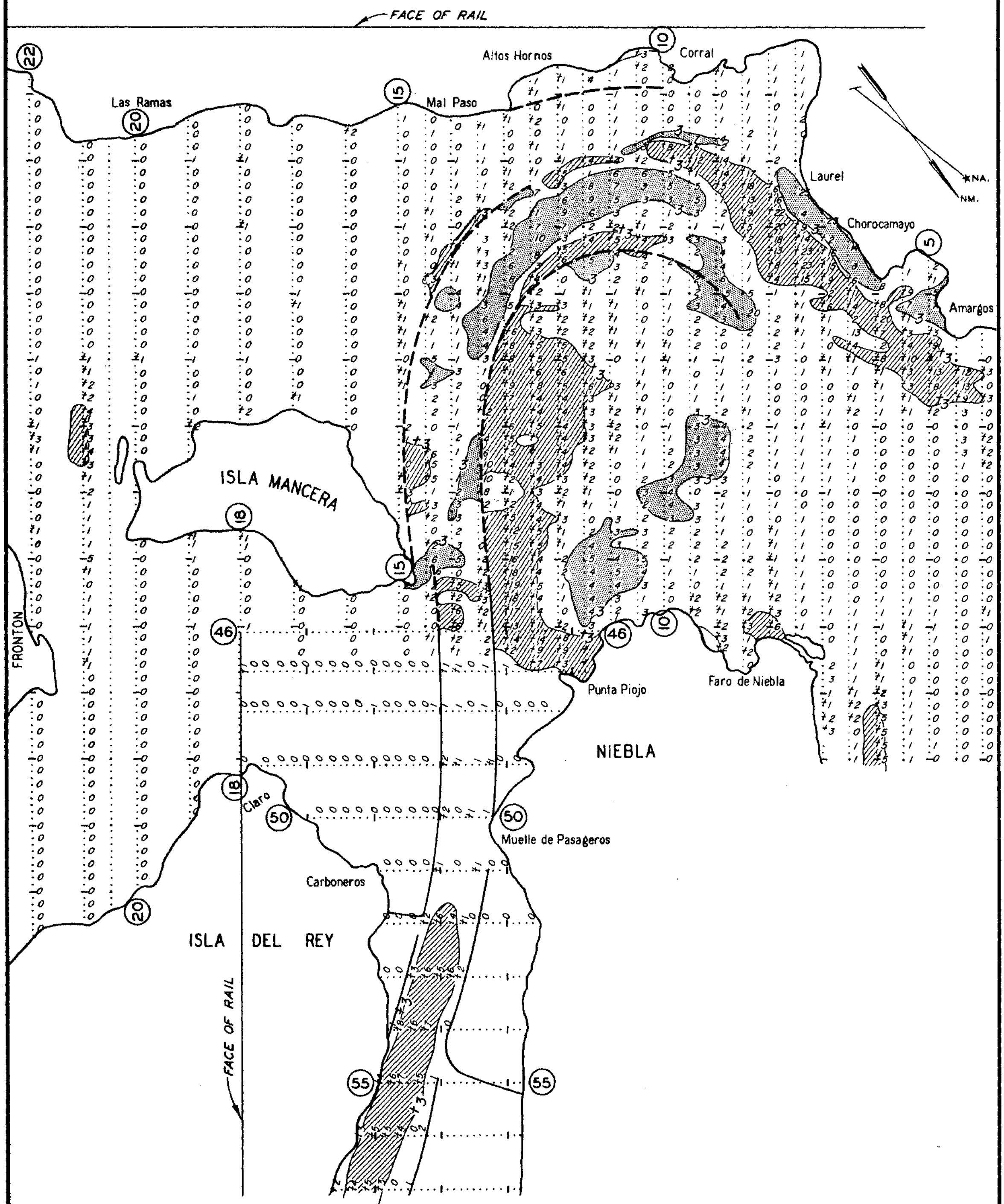
NOTE: SOUNDINGS ARE IN FEET BELOW MEAN LOWER LOW WATER (MLLW). CONTOURS ARE IN METERS BELOW MLLW.

PLAN 2
CONDITION OF MOVABLE BED AT END OF TEST
DURATION OF TEST 12 YEARS

SCALES

PROTOTYPE 1000 0 1000 2000 FT

MODEL 1 0 1 2 3 4 5 FT



LEGEND

- EXISTING STRUCTURE
- PROPOSED STRUCTURE
- MORE THAN 3 FEET OF FILL
- LESS THAN 3 FEET OF SCOUR OR FILL
- MORE THAN 3 FEET OF SCOUR
- (15) SOUNDING RANGE

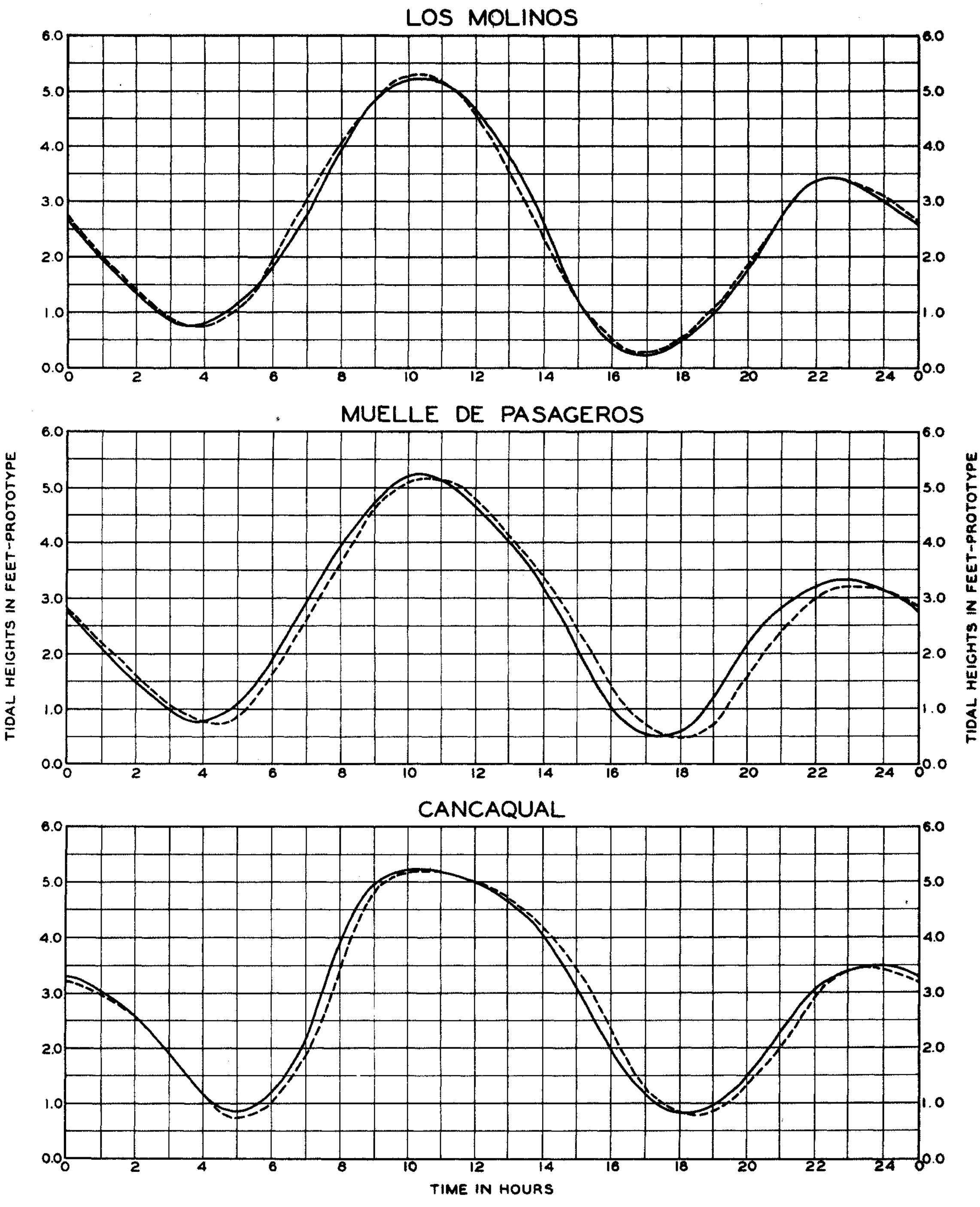
NOTE: VALUES SHOWN REPRESENT THE TOTAL CHANGE IN FEET FROM START TO END OF TEST.

PLAN 2
SCOUR AND FILL DURING TEST

SCALES

PROTOTYPE 1000 0 1000 2000 FT

MODEL 1 0 1 2 3 4 5 FT



LEGEND

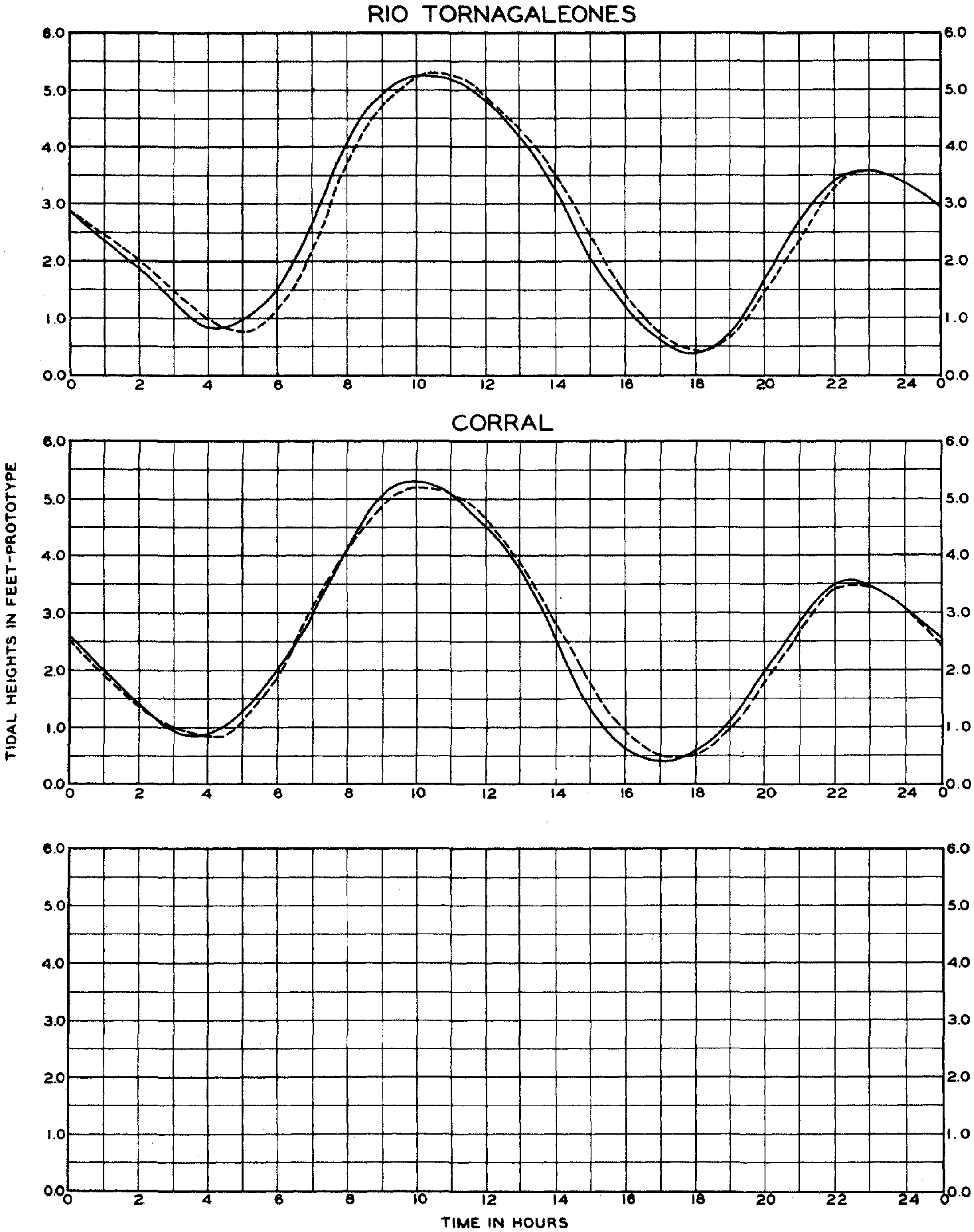
——— BASE TEST TIDAL HEIGHTS

------ PLAN TIDAL HEIGHTS

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF CORRAL MERIDIAN.

TIDAL HEIGHTS REFERRED TO MEAN LOWER LOW WATER AT LOS MOLINOS.

TIDE CURVES
PLAN 2
LOS MOLINOS, MUELLE DE PASAGEROS AND CANCAQUAL



LEGEND

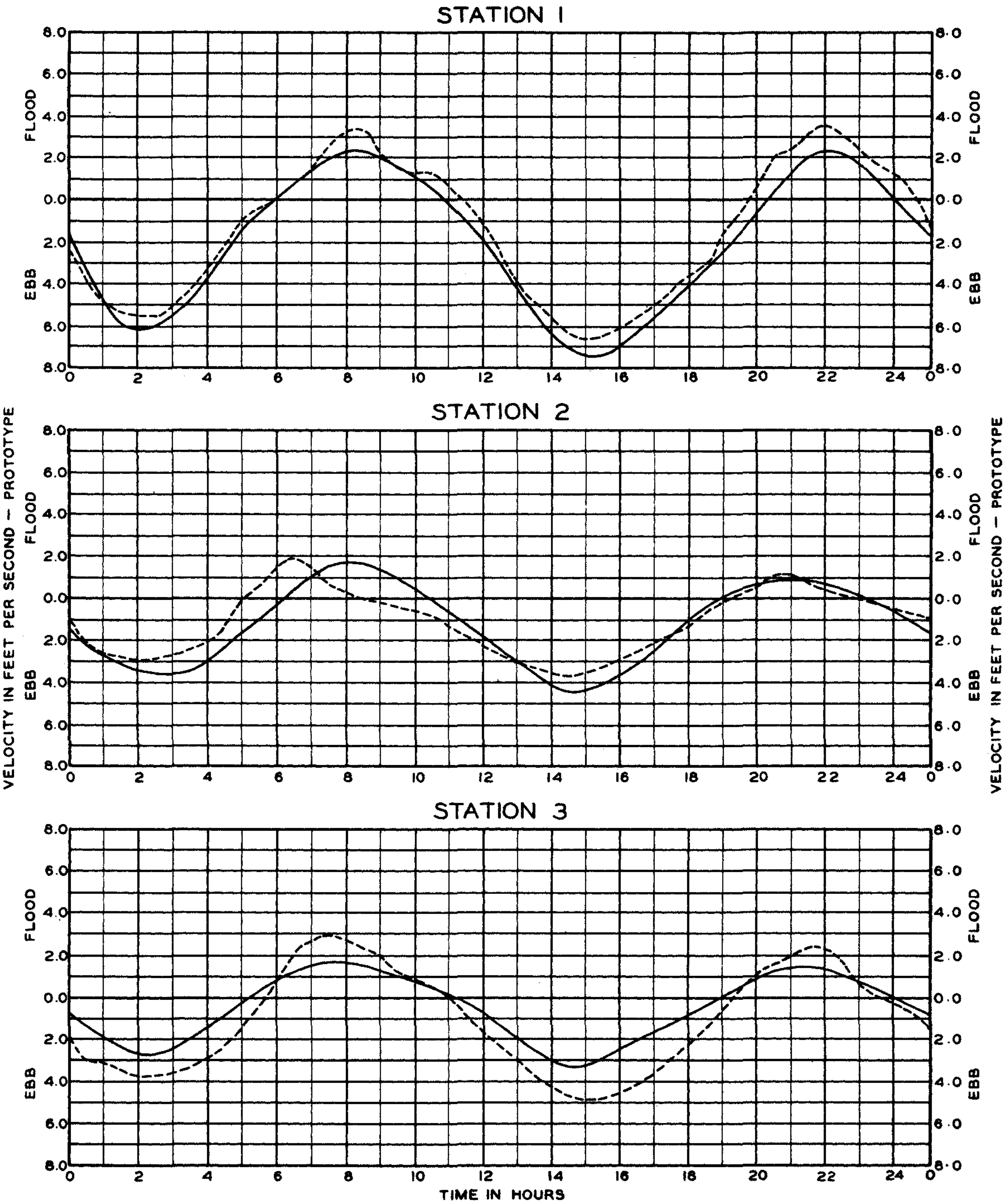
——— BASE TEST TIDAL HEIGHTS

------- PLAN TIDAL HEIGHTS

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF CORRAL MERIDIAN.

TIDAL HEIGHTS REFERRED TO MEAN LOWER LOW WATER AT LOS MOLINOS.

TIDE CURVES
PLAN 2
RIO TORNAGALEONES AND CORRAL

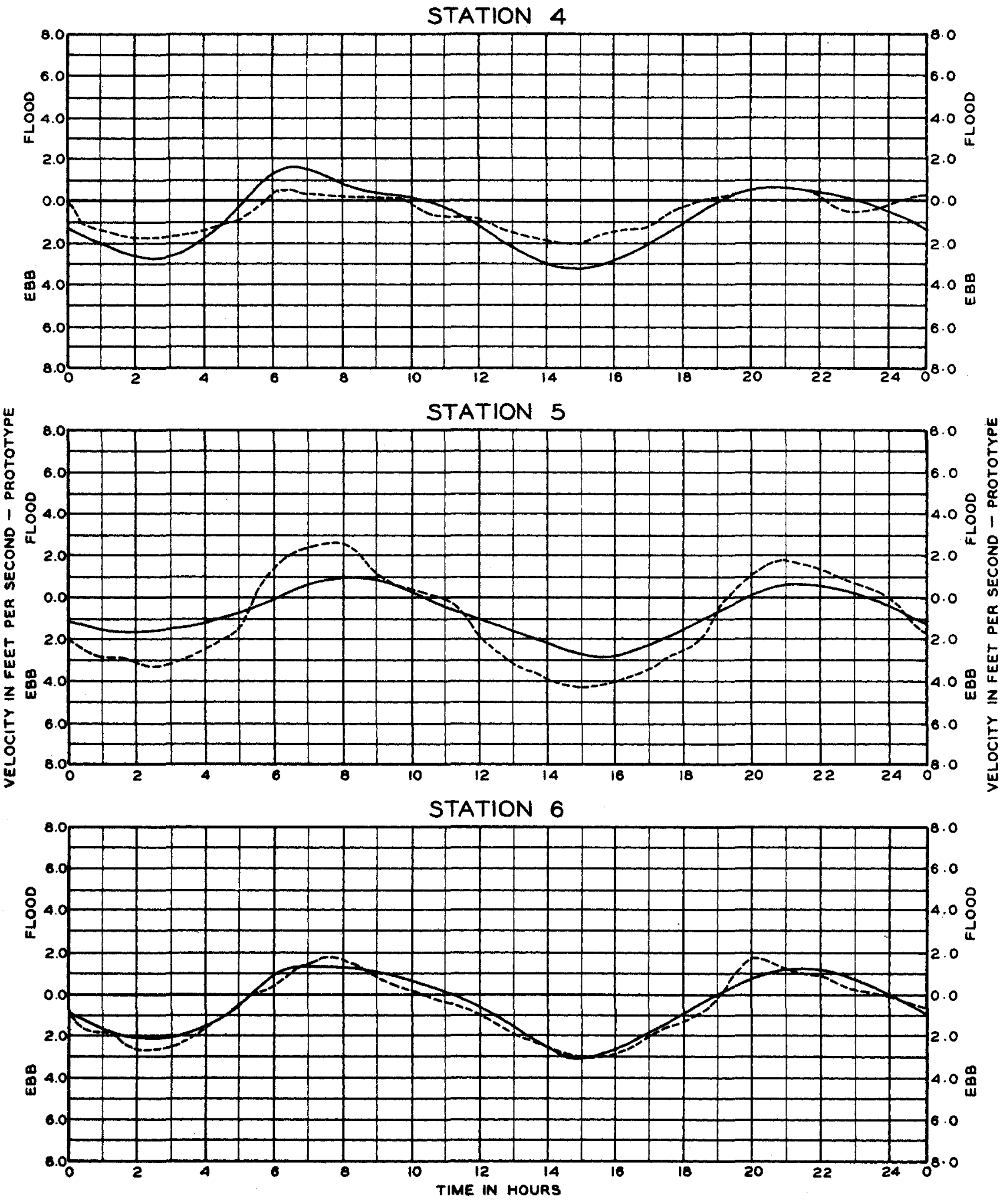


LEGEND

——— BASE TEST VELOCITY CURVES
- - - - - PLAN VELOCITY CURVES

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF CORRAL MERIDIAN.

VELOCITY CURVES
PLAN 2
STATIONS 1 TO 3



LEGEND

——— BASE TEST VELOCITY CURVES
------- PLAN VELOCITY CURVES

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF CORRAL MERIDIAN.

VELOCITY CURVES
PLAN 2
STATIONS 4 TO 6

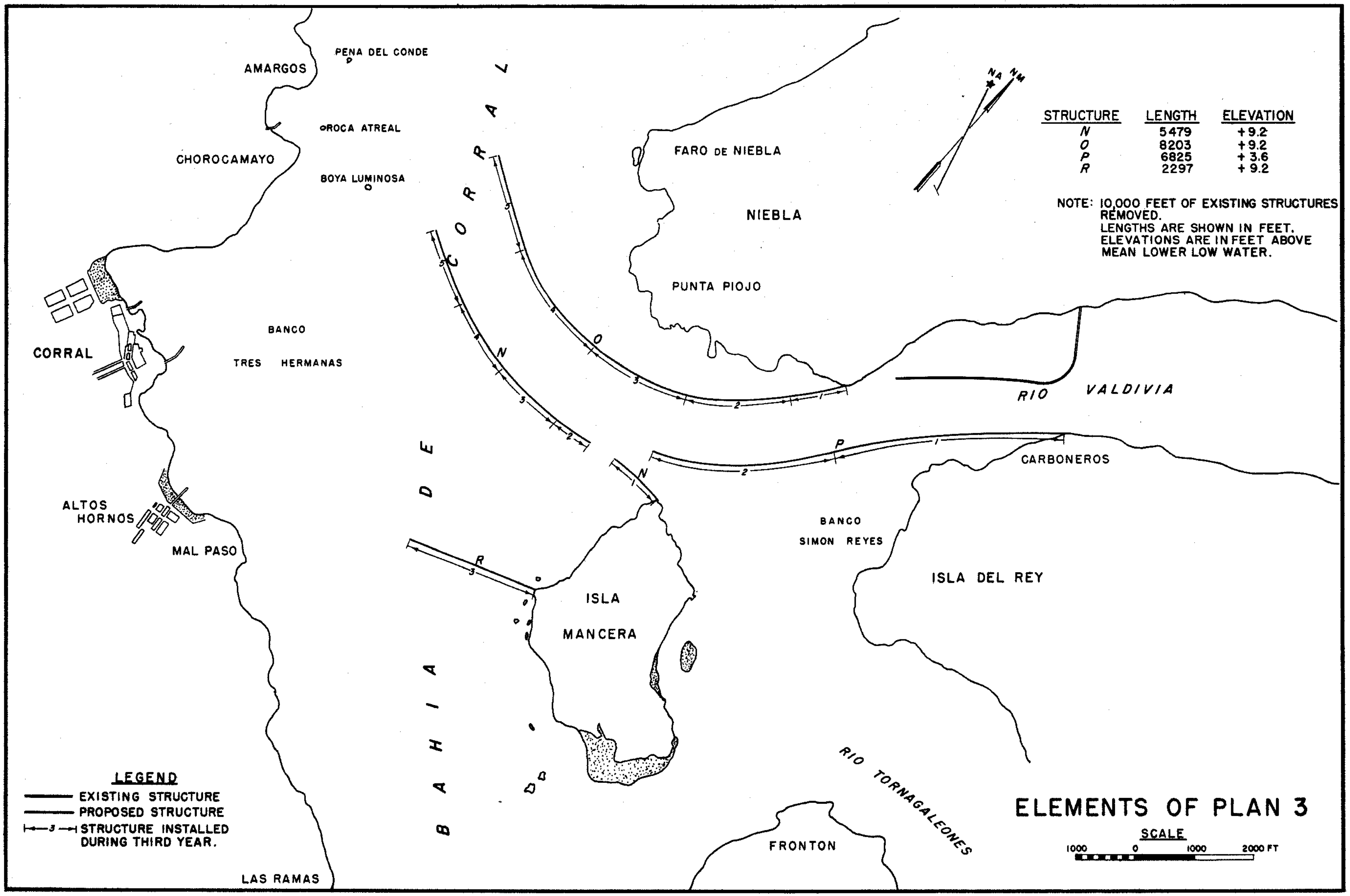
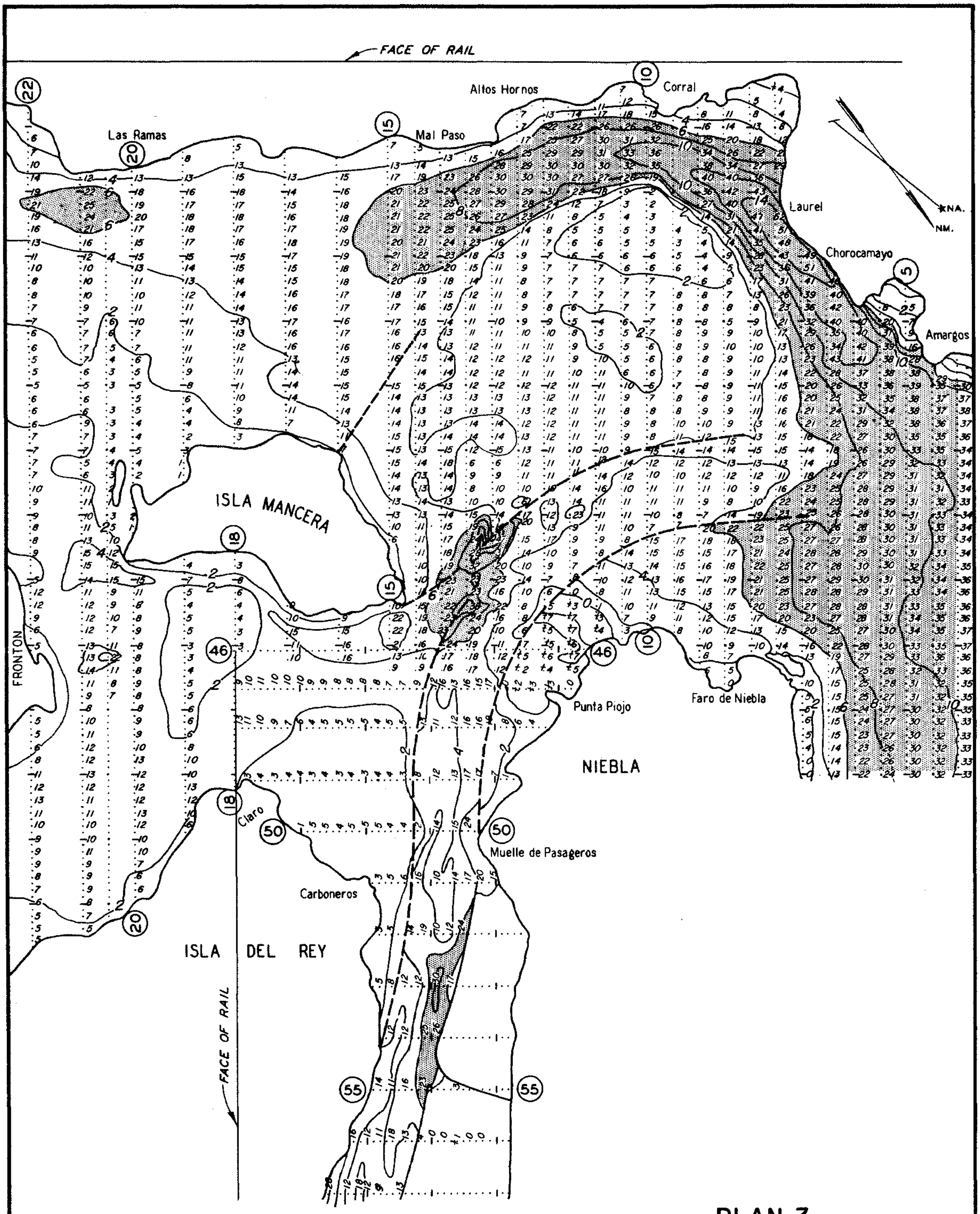

ELEMENTS OF PLAN 3
STRUCTURE LENGTH ELEVATION
N 5479 +9.2
O 8203 +9.2
P 6825 +3.6
R 2297 +9.2
NOTE: 10,000 FEET OF EXISTING STRUCTURES REMOVED.
LENGTHS ARE SHOWN IN FEET.
ELEVATIONS ARE IN FEET ABOVE MEAN LOWER LOW WATER.
LEGEND
EXISTING STRUCTURE
PROPOSED STRUCTURE
STRUCTURE INSTALLED DURING THIRD YEAR.
SCALE
1000 0 1000 2000 FT
NA
NM
AMARGOS
PENA DEL CONDE
ROCA ATREAL
CHOROCAMAYO
BOYA LUMINOSA
CORRAL
BANCO
TRES HERMANAS
ALTOS HORNOS
MAL PASO
LAS RAMAS
BAHIA DE CORRAL
FARO DE NIEBLA
NIEBLA
PUNTA PIOJO
RIO VALDIVIA
CARBONEROS
BANCO
SIMON REYES
ISLA DEL REY
ISLA MANCERA
RIO TORNAGALEONES
FRONTON

PLATE 25



LEGEND

—— EXISTING STRUCTURE
– – – PROPOSED STRUCTURE
MORE THAN 6 METERS DEEP MLLW
LESS THAN 6 METERS DEEP MLLW
(15) SOUNDING RANGE

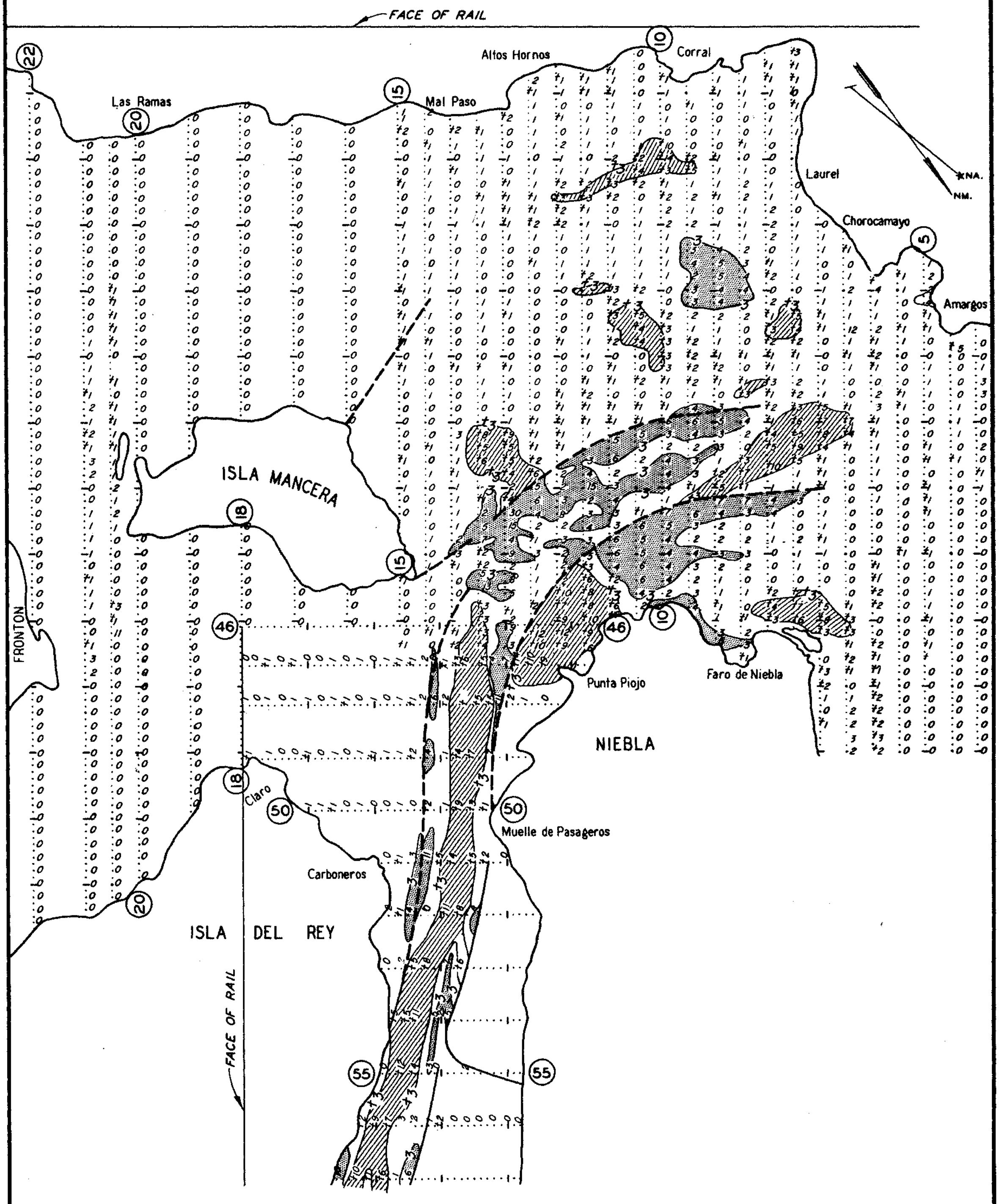
NOTE: SOUNDINGS ARE IN FEET BELOW MEAN LOWER LOW WATER (MLLW). CONTOURS ARE IN METERS BELOW MLLW.

PLAN 3
CONDITION OF MOVABLE BED AT END OF TEST
DURATION OF TEST 12 YEARS

SCALES

PROTOTYPE 1000 0 1000 2000 FT

MODEL 1 0 1 2 3 4 5 FT



LEGEND

- EXISTING STRUCTURE
- PROPOSED STRUCTURE
- MORE THAN 3 FEET FILL
- LESS THAN 3 FEET SCOUR OR FILL
- MORE THAN 3 FEET OF SCOUR
- (15) SOUNDING RANGE

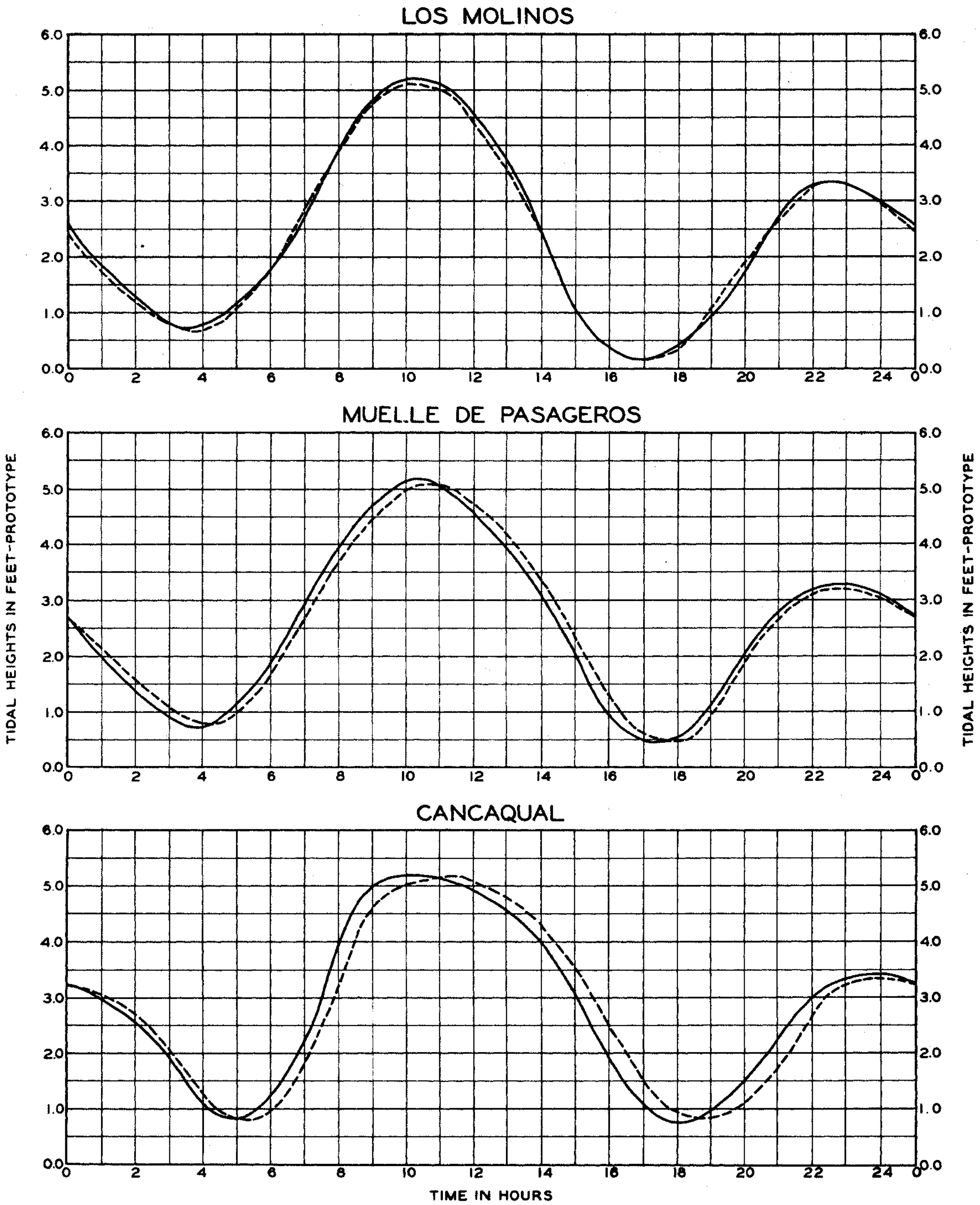
NOTE: VALUES SHOWN REPRESENT THE TOTAL CHANGE IN FEET FROM START TO END OF TEST.

PLAN 3
SCOUR AND FILL DURING TEST

SCALES

PROTOTYPE 1000 0 1000 2000 FT

MODEL 1 0 1 2 3 4 5 FT



LEGEND

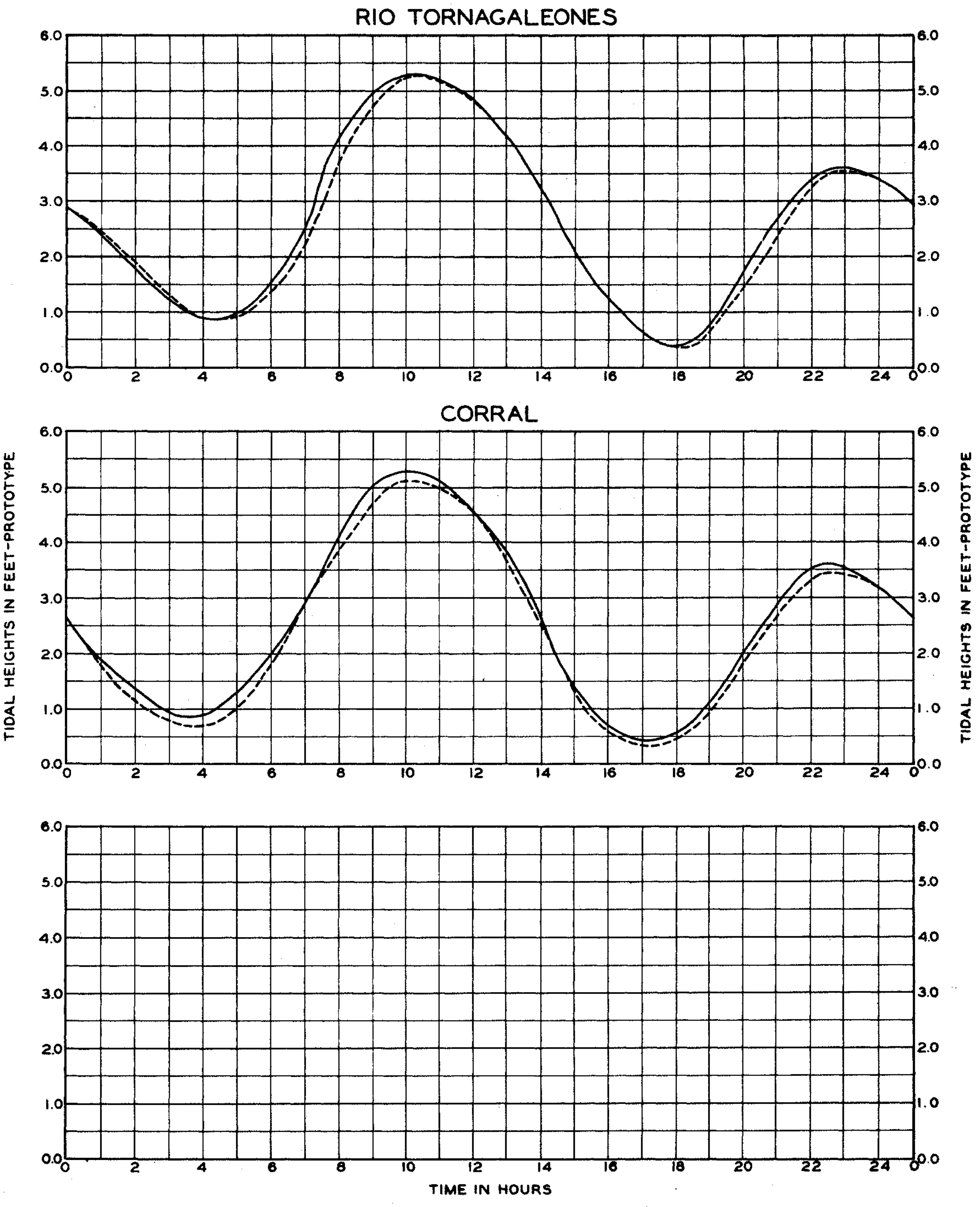
——— BASE TEST TIDAL HEIGHTS

- - - - - PLAN TIDAL HEIGHTS

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF CORRAL MERIDIAN.

TIDAL HEIGHTS REFERRED TO MEAN LOWER LOW WATER AT LOS MOLINOS.

TIDE CURVES
PLAN 3
LOS MOLINOS, MUELLE DE PASAGEROS AND CANCAQUAL



LEGEND

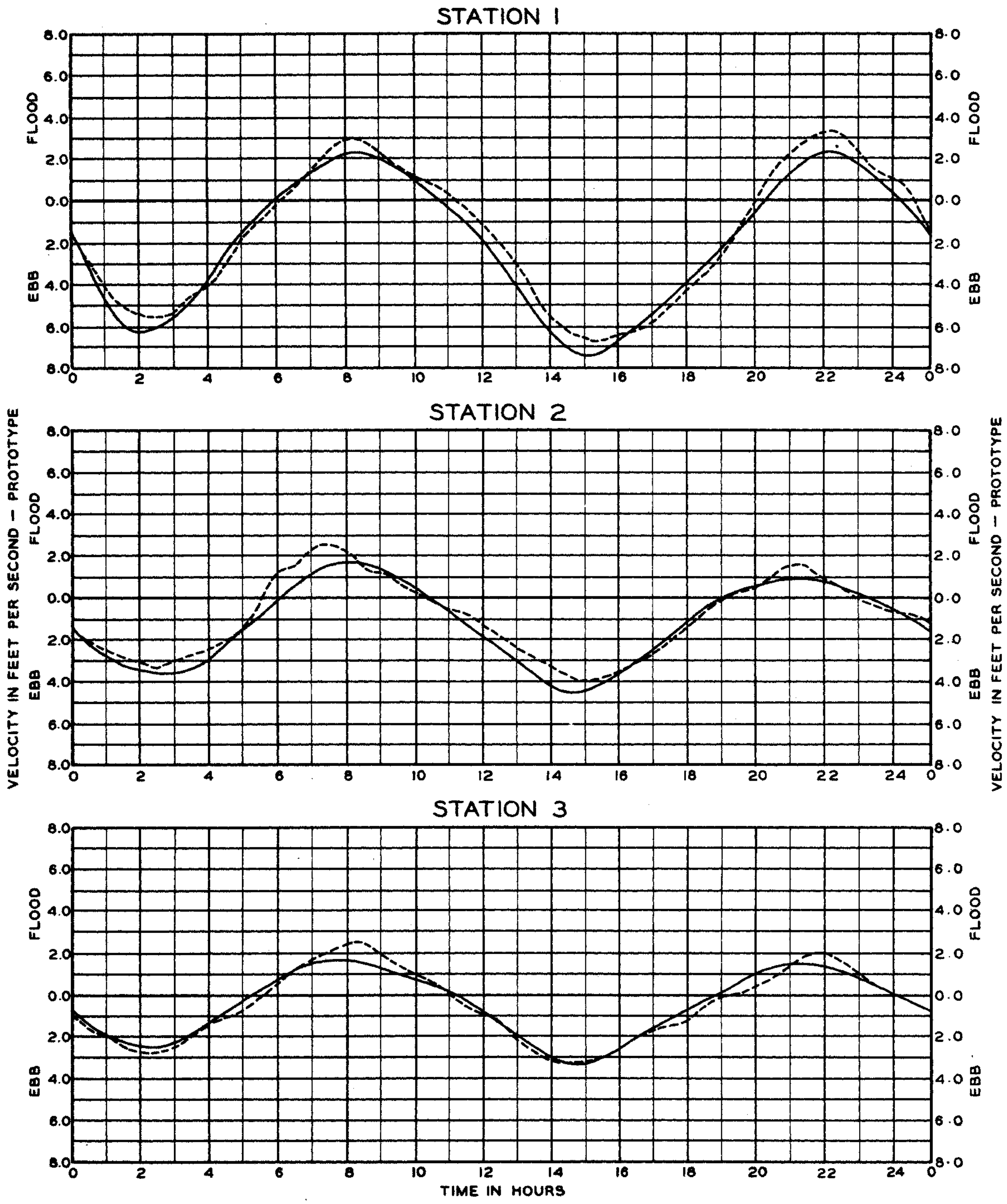
——— BASE TEST TIDAL HEIGHTS

- - - - - PLAN TIDAL HEIGHTS

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF CORRAL MERIDIAN.

TIDAL HEIGHTS REFERRED TO MEAN LOWER LOW WATER AT LOS MOLINOS.

TIDE CURVES
PLAN 3
RIO TORNAGALEONES AND CORRAL



LEGEND

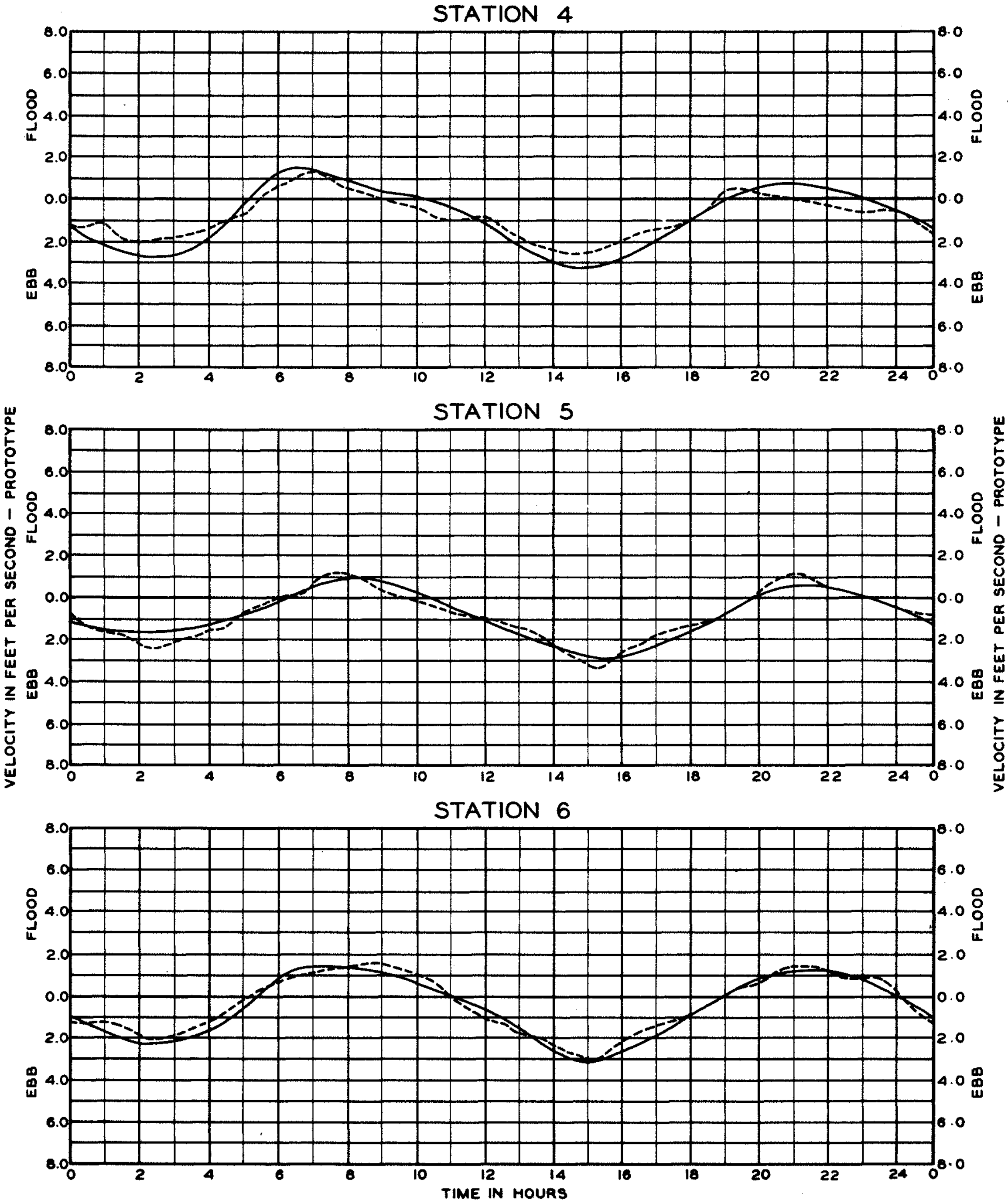
——— BASE TEST VELOCITY CURVES
------ PLAN VELOCITY CURVES

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF CORRAL MERIDIAN.

VELOCITY CURVES

PLAN 3

STATIONS 1 TO 3



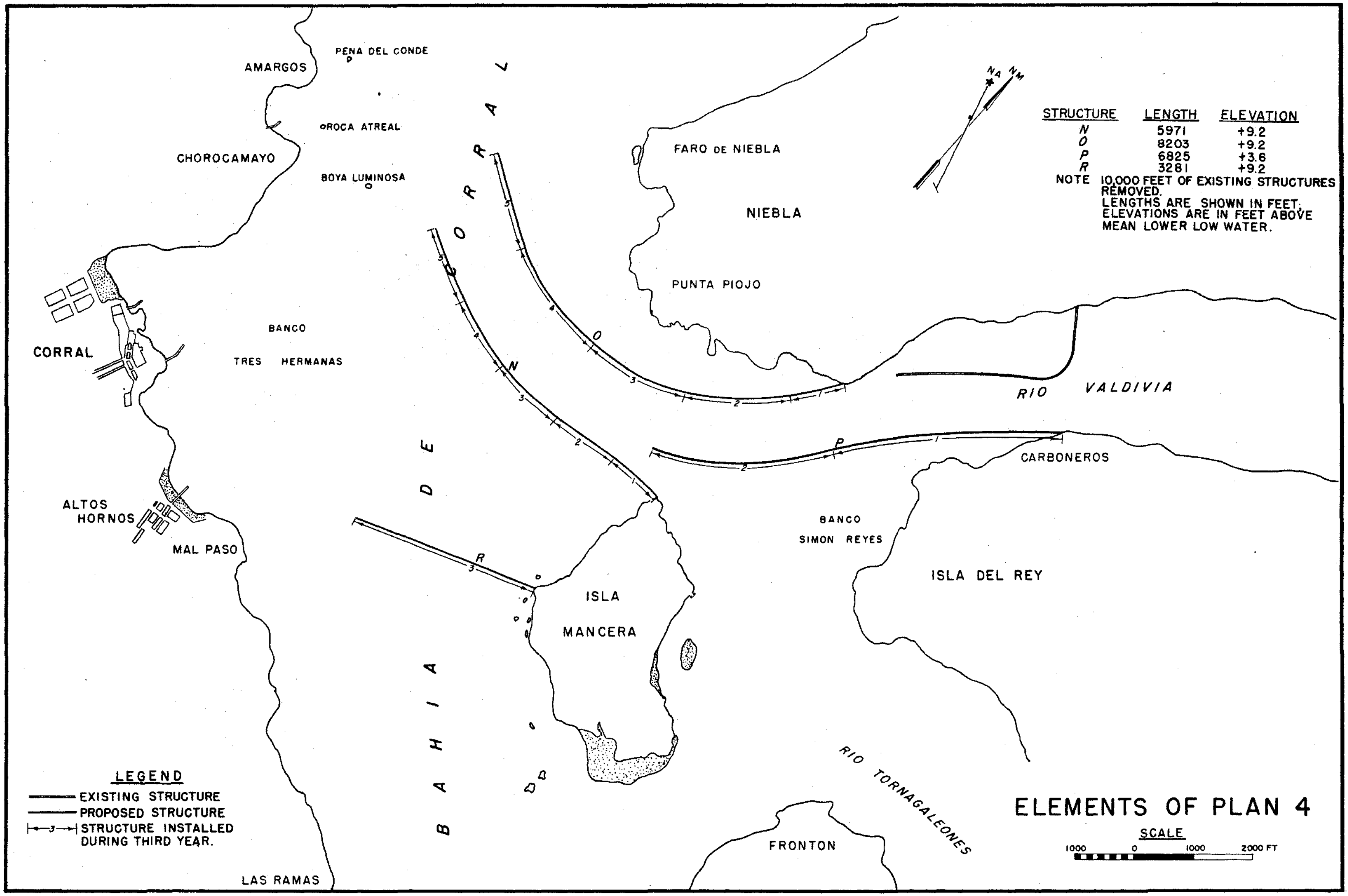
LEGEND

——— BASE TEST VELOCITY CURVES
------ PLAN VELOCITY CURVES

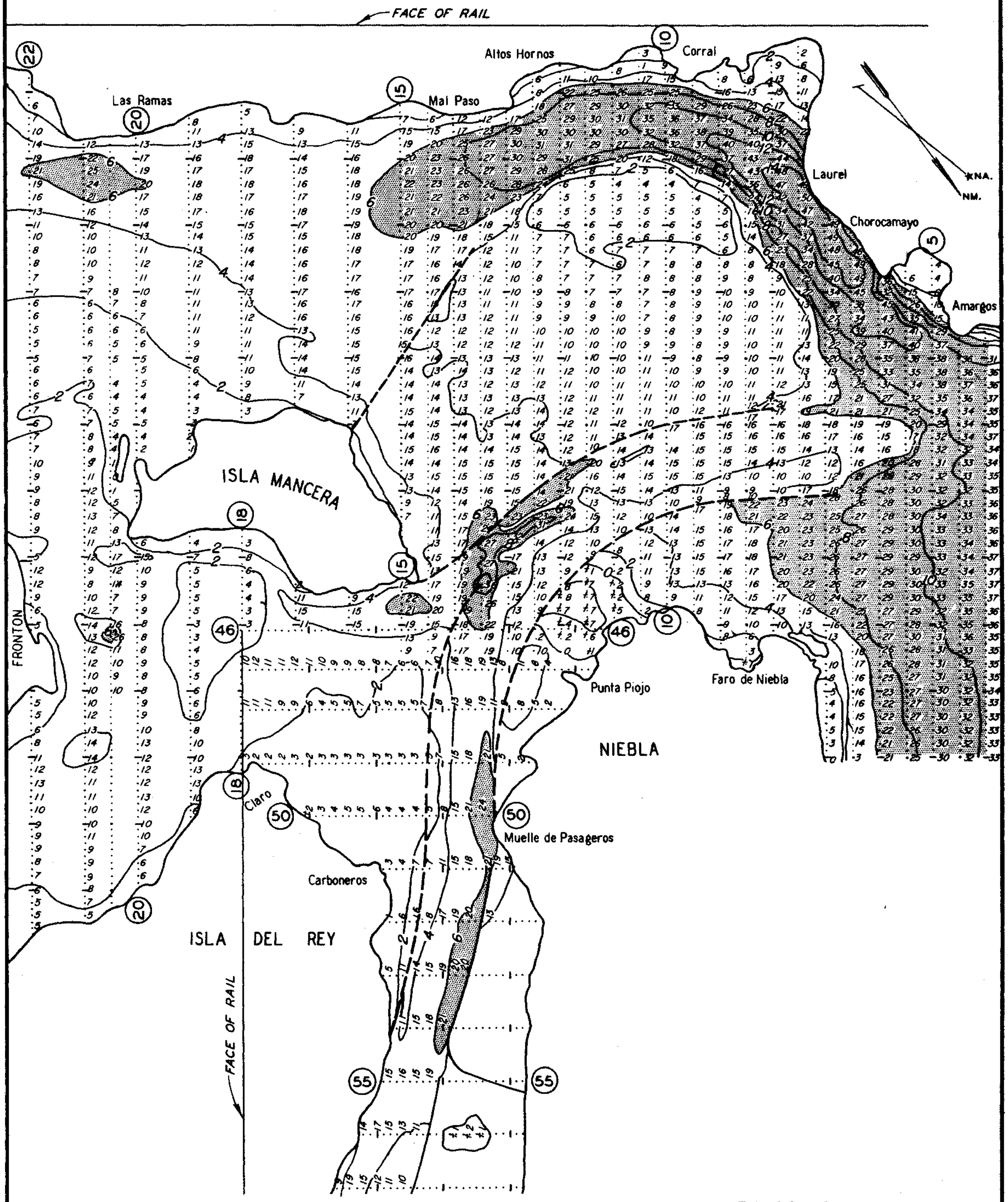
NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF CORRAL MERIDIAN.

VELOCITY CURVES
PLAN 3
STATIONS 4 TO 6

PLATE 32



ELEMENTS OF PLAN 4



PLAN 4
CONDITION OF MOVABLE BED AT END OF TEST
DURATION OF TEST 12 YEARS

LEGEND

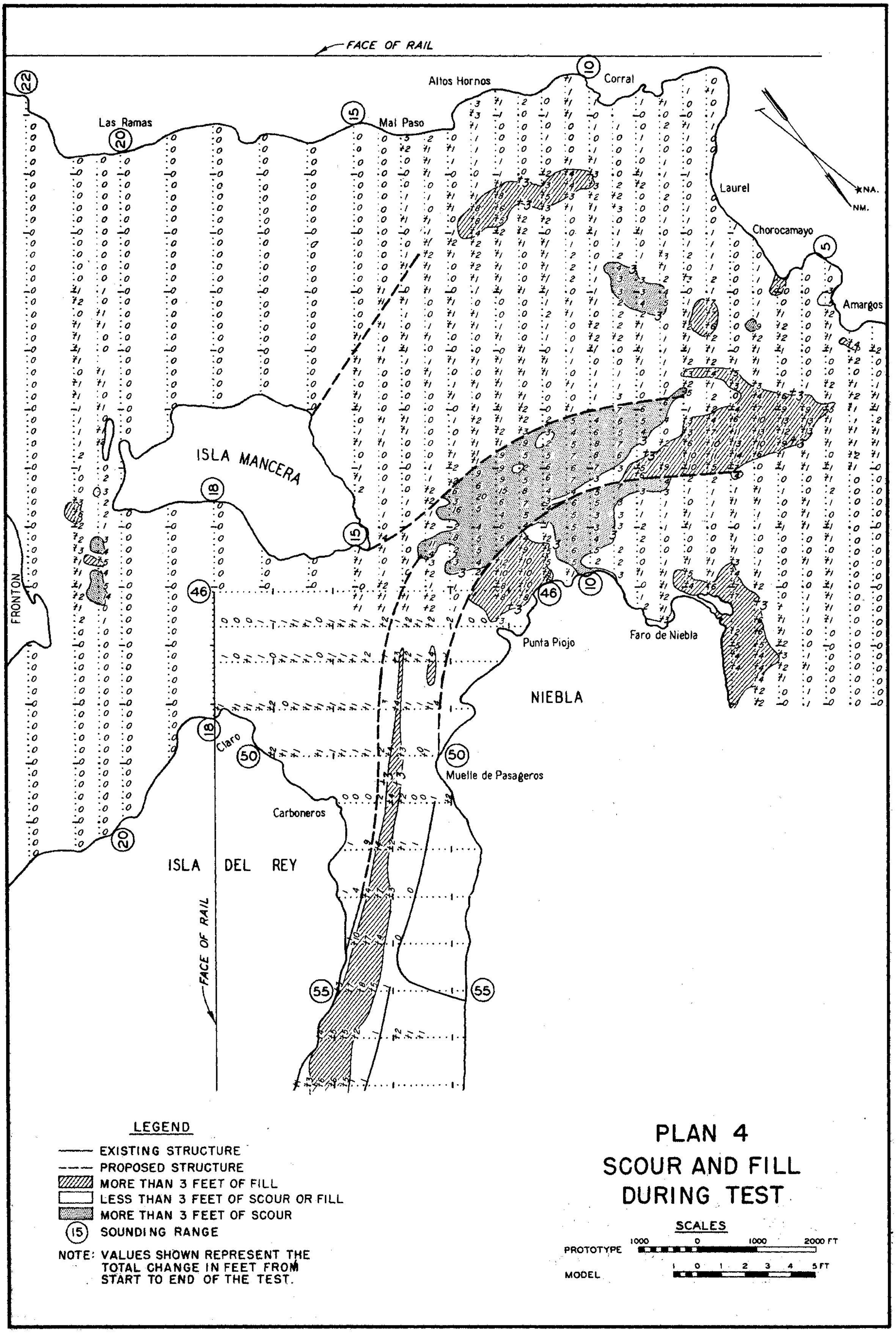
- EXISTING STRUCTURE
- PROPOSED STRUCTURE
- MORE THAN 6 METERS DEEP MLLW
- LESS THAN 6 METERS DEEP MLLW
- (15) SOUNDING RANGE

NOTE: SOUNDINGS ARE IN FEET BELOW MEAN LOWER LOW WATER (MLLW). CONTOURS ARE IN METERS BELOW MLLW.

SCALES

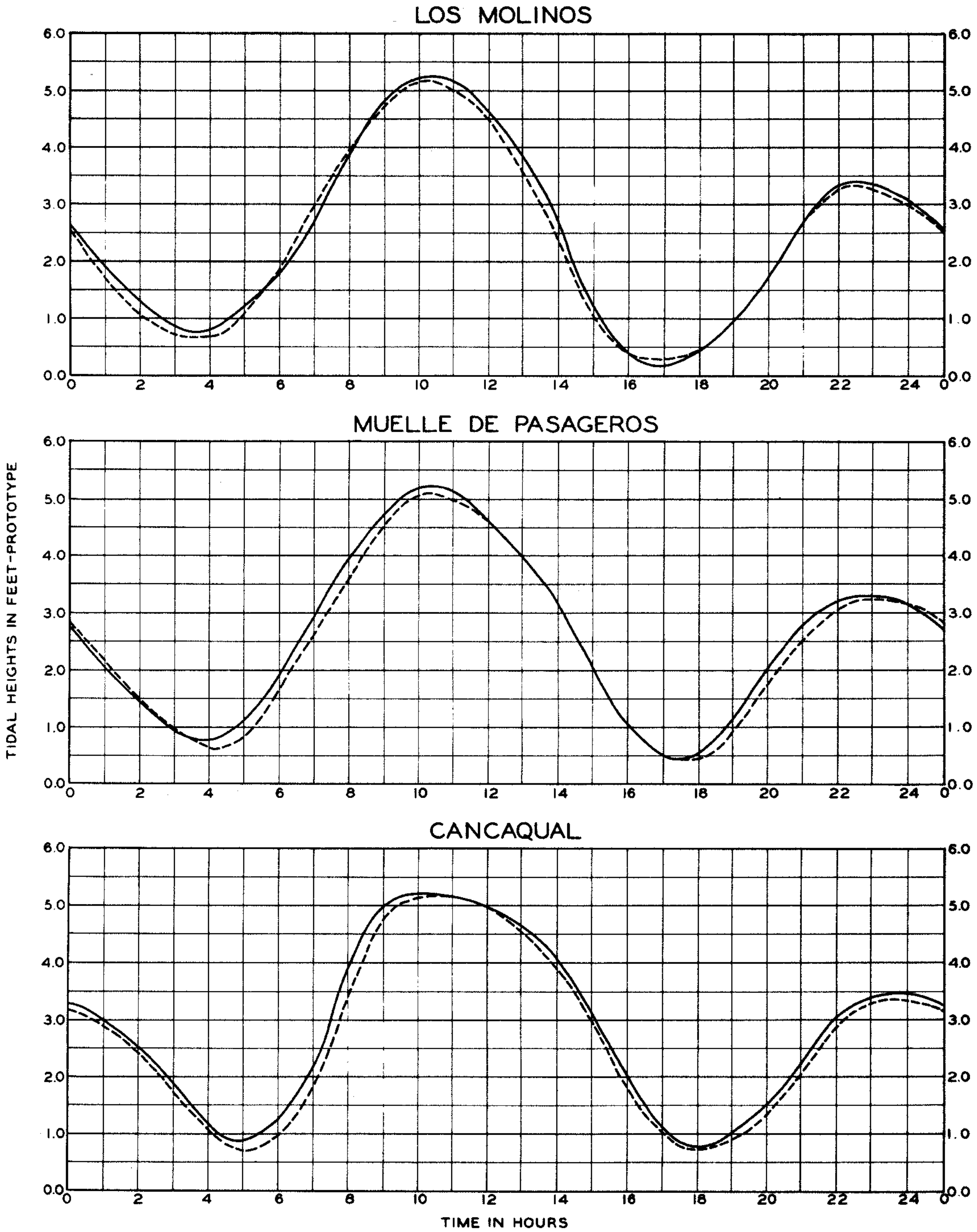
PROTOTYPE 1000 0 1000 2000 FT

MODEL 1 0 1 2 3 4 5 FT



PLAN 4
SCOUR AND FILL
DURING TEST

PLATE 34



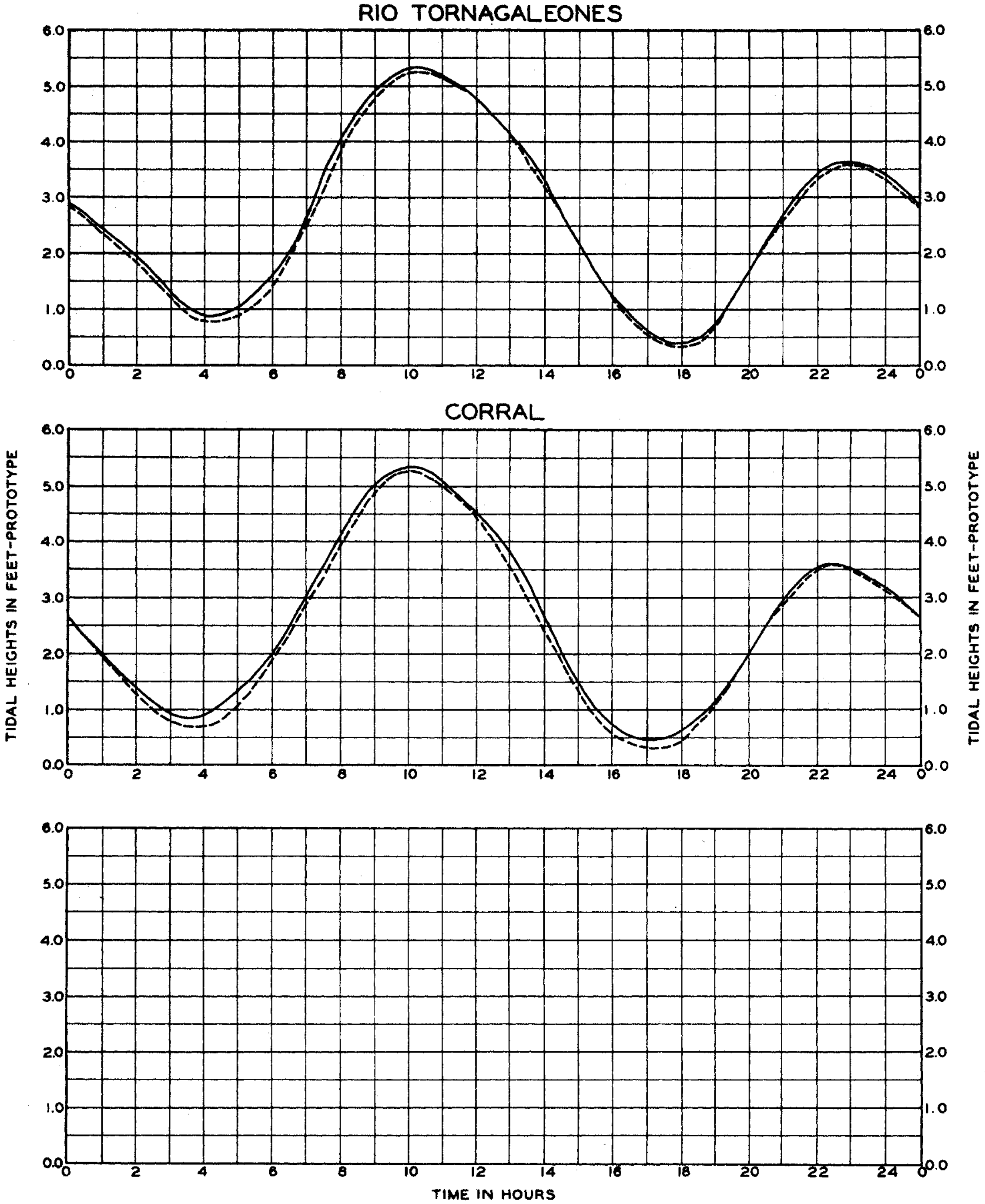
LEGEND

——— BASE TEST TIDAL HEIGHTS
- - - - - PLAN TIDAL HEIGHTS

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF CORRAL MERIDIAN.

TIDAL HEIGHTS REFERRED TO MEAN LOWER LOW WATER AT LOS MOLINOS.

TIDE CURVES
PLAN 4
LOS MOLINOS, MUELLE DE PASAGEROS AND CANCAQUAL



LEGEND

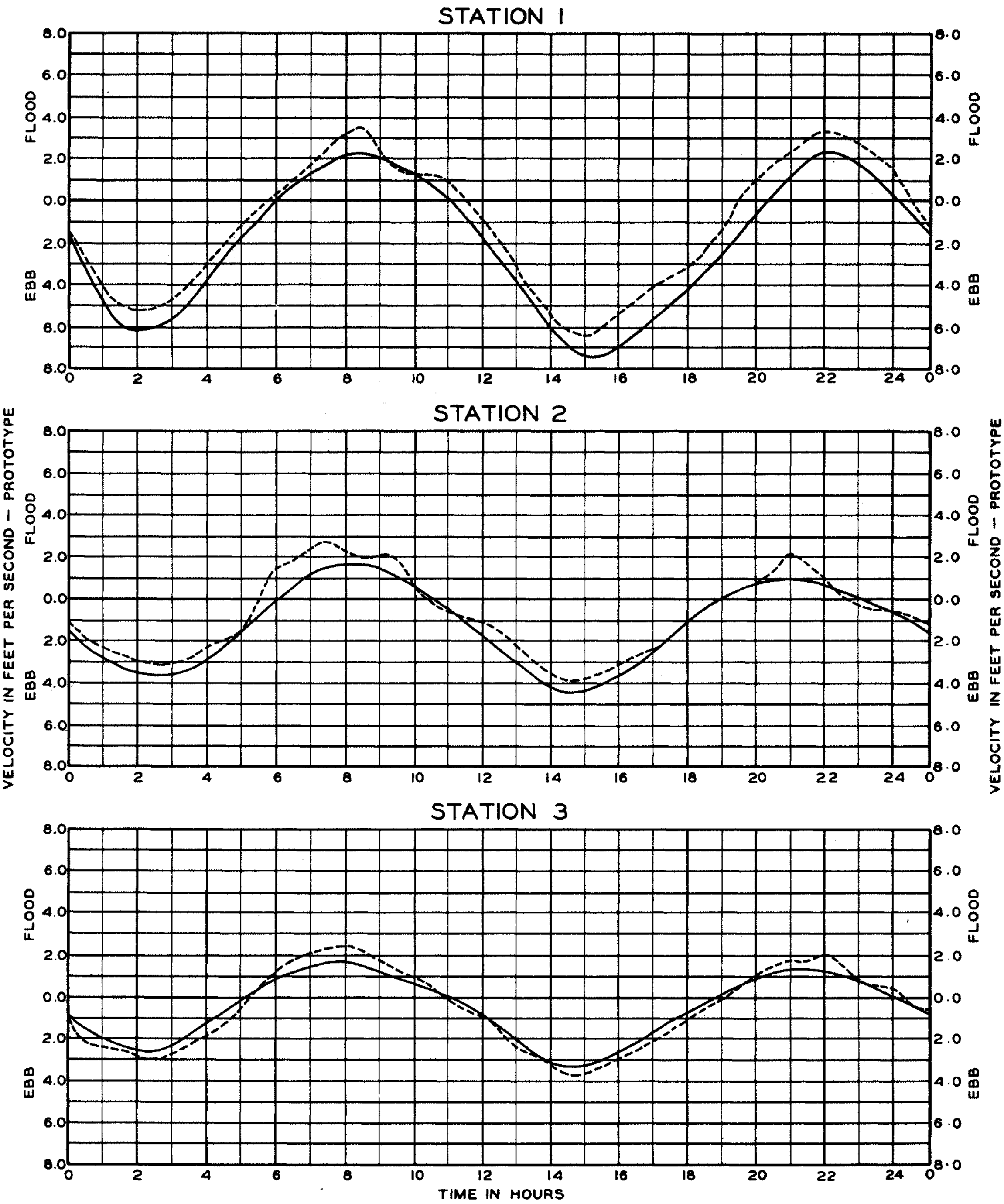
——— BASE TEST TIDAL HEIGHTS

- - - - PLAN TIDAL HEIGHTS

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF CORRAL MERIDIAN.

TIDAL HEIGHTS REFERRED TO MEAN LOWER LOW WATER AT LOS MOLINOS.

TIDE CURVES
PLAN 4
RIO TORNAGALEONES AND CORRAL

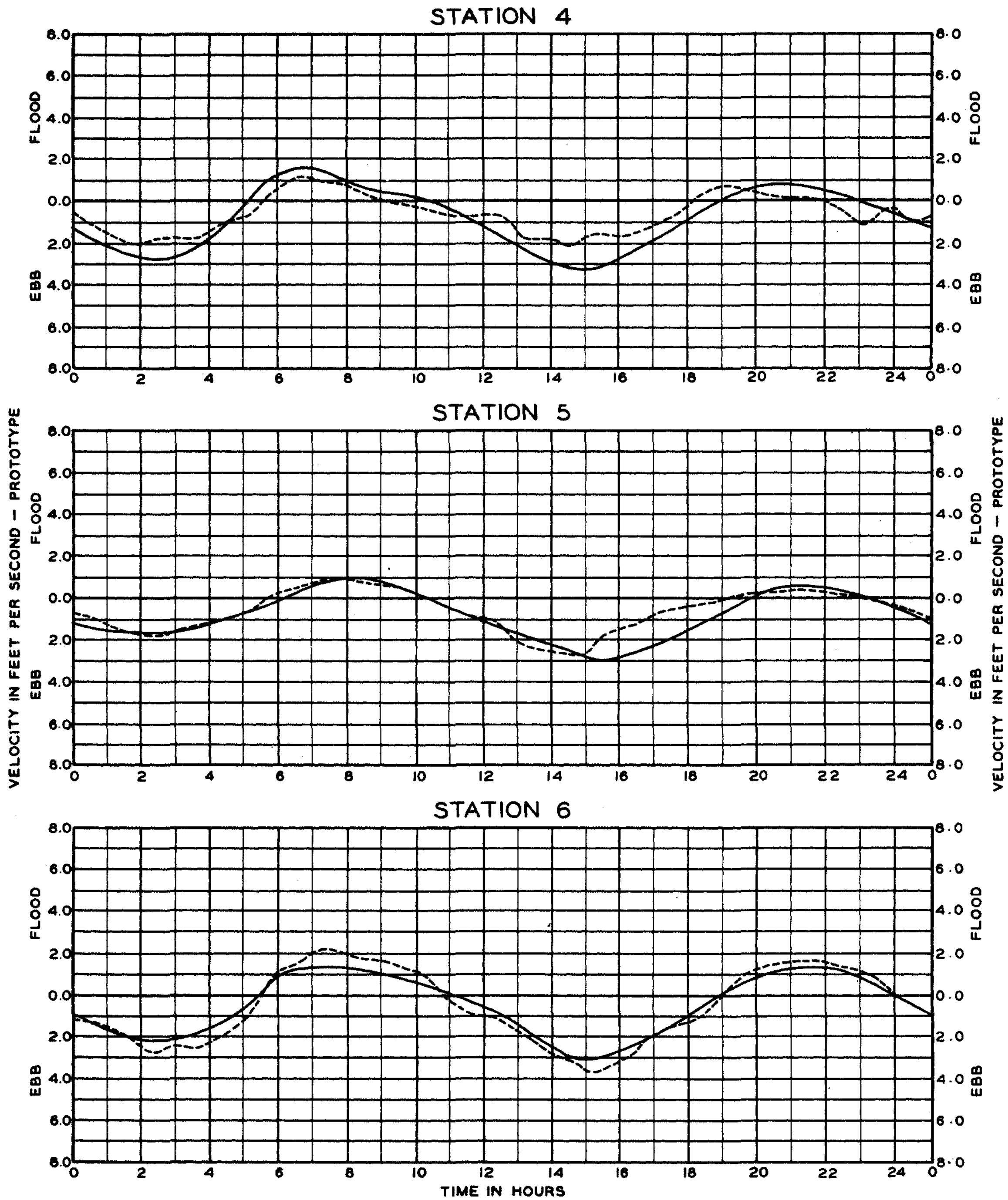


LEGEND

——— BASE TEST VELOCITY CURVES
- - - - - - PLAN VELOCITY CURVES

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF CORRAL MERIDIAN.

VELOCITY CURVES
PLAN 4
STATIONS 1 TO 3



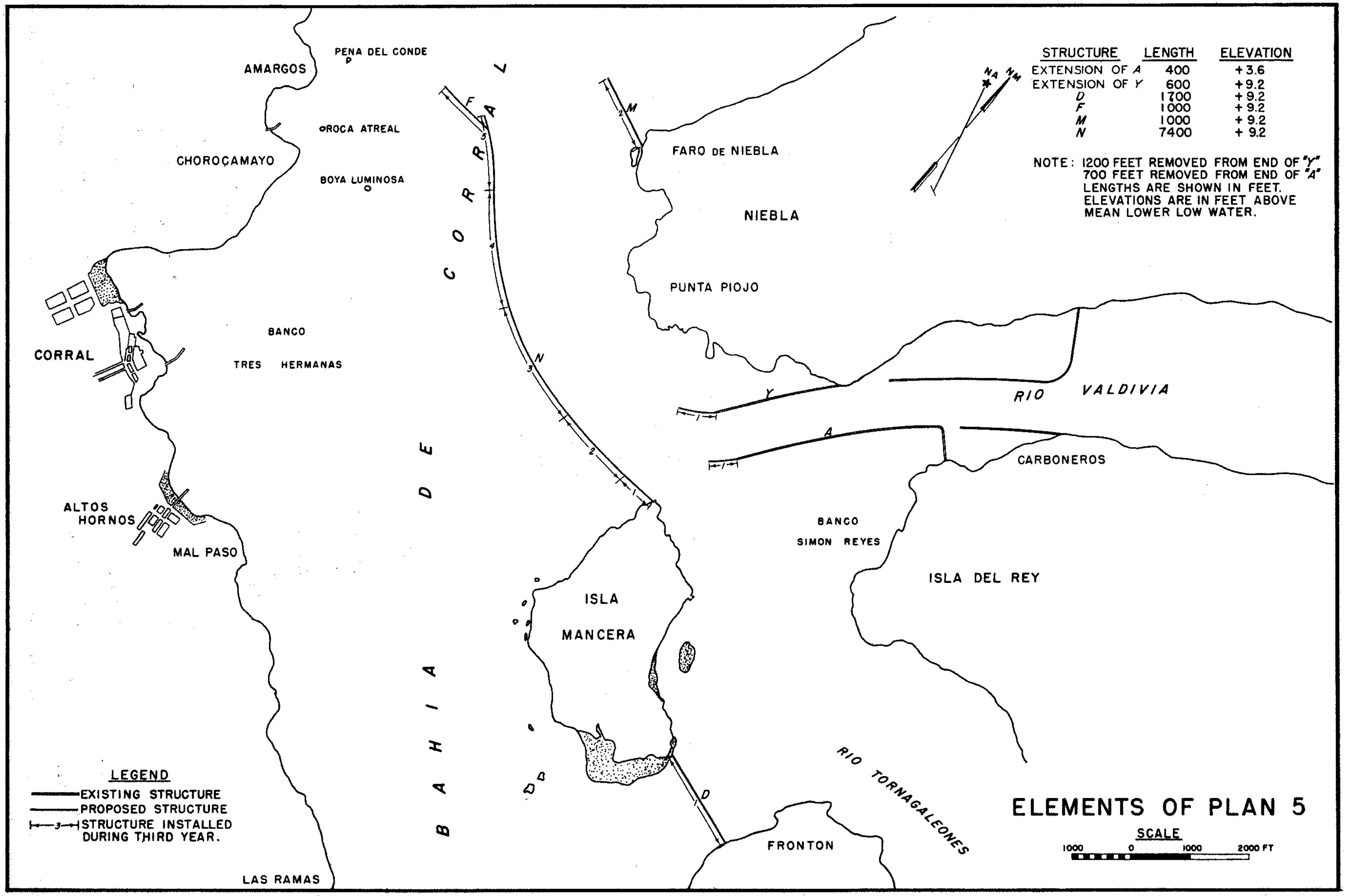
LEGEND

———— BASE TEST VELOCITY CURVES

------- PLAN VELOCITY CURVES

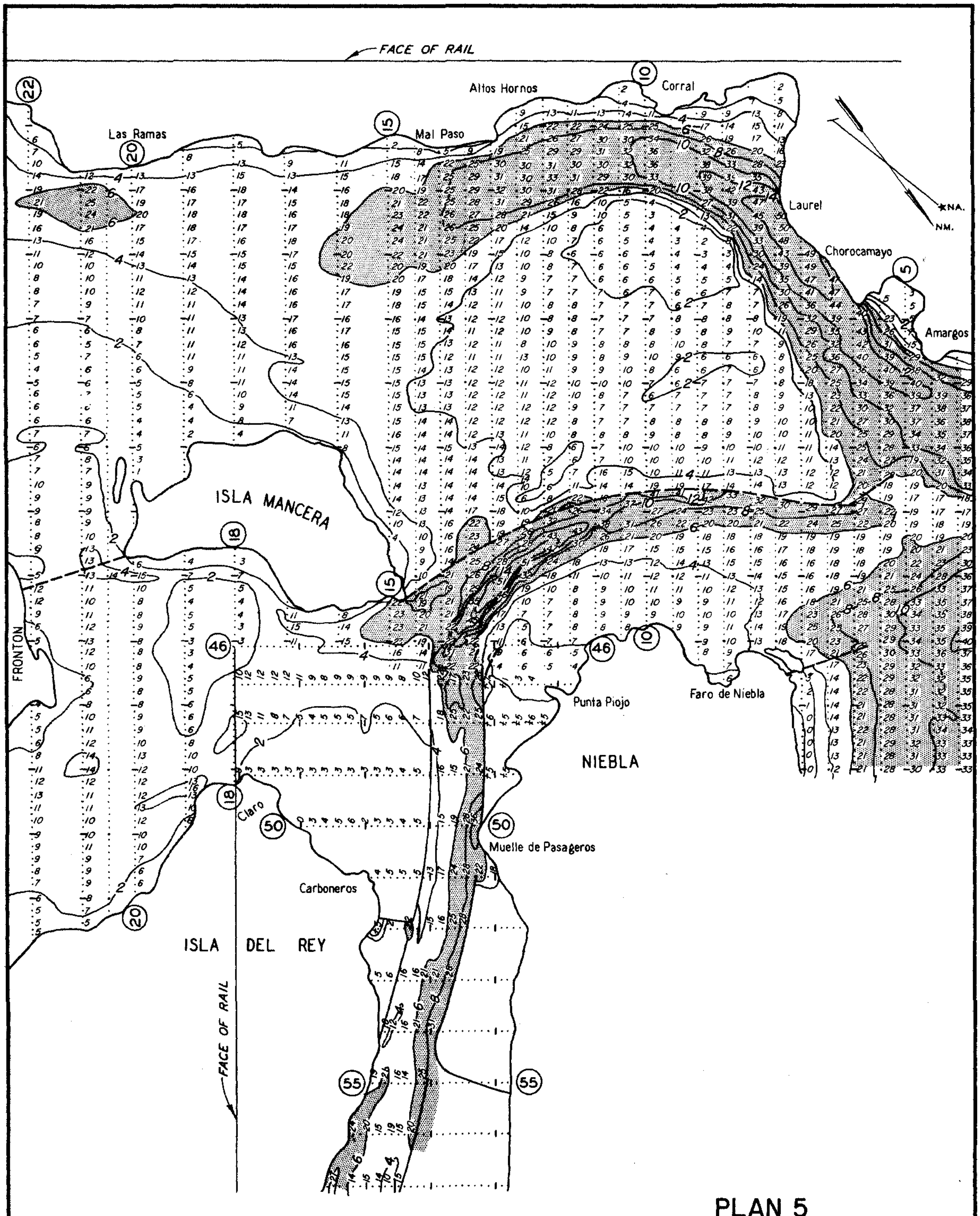
NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF CORRAL MERIDIAN.

VELOCITY CURVES
PLAN 4
STATIONS 4 TO 6



STRUCTURE LENGTH ELEVATION
EXTENSION OF A 400 +3.6
EXTENSION OF Y 600 +9.2
D 1700 +9.2
F 1000 +9.2
M 1000 +9.2
N 7400 + 9.2
NOTE: 1200 FEET REMOVED FROM END OF "Y"
700 FEET REMOVED FROM END OF "A"
LENGTHS ARE SHOWN IN FEET.
ELEVATIONS ARE IN FEET ABOVE MEAN LOWER LOW WATER.
NA
NM
AMARGOS
PENA DEL CONDE
ROCA ATREAL
CHOROÇAMAYO
BOYA LUMINOSA
FARO DE NIEBLA
NIEBLA
PUNTA PIOJO
BANCO
TRES HERMANAS
CORRAL
BAHIA DE CORRAL
RIO VALDIVIA
CARBONEROS
ALTOS HORNOS
MAL PASO
BANCO
SIMON REYES
ISLA DEL REY
ISLA
MANCERA
RIO TORNAGALEONES
FRONTON
LAS RAMAS
LEGEND
EXISTING STRUCTURE
PROPOSED STRUCTURE
STRUCTURE INSTALLED DURING THIRD YEAR.
ELEMENTS OF PLAN 5
SCALE
1000 0 1000 2000 FT

PLATE 39



PLAN 5
CONDITION OF MOVABLE BED AT END OF TEST
DURATION OF TEST 12 YEARS

SCALES

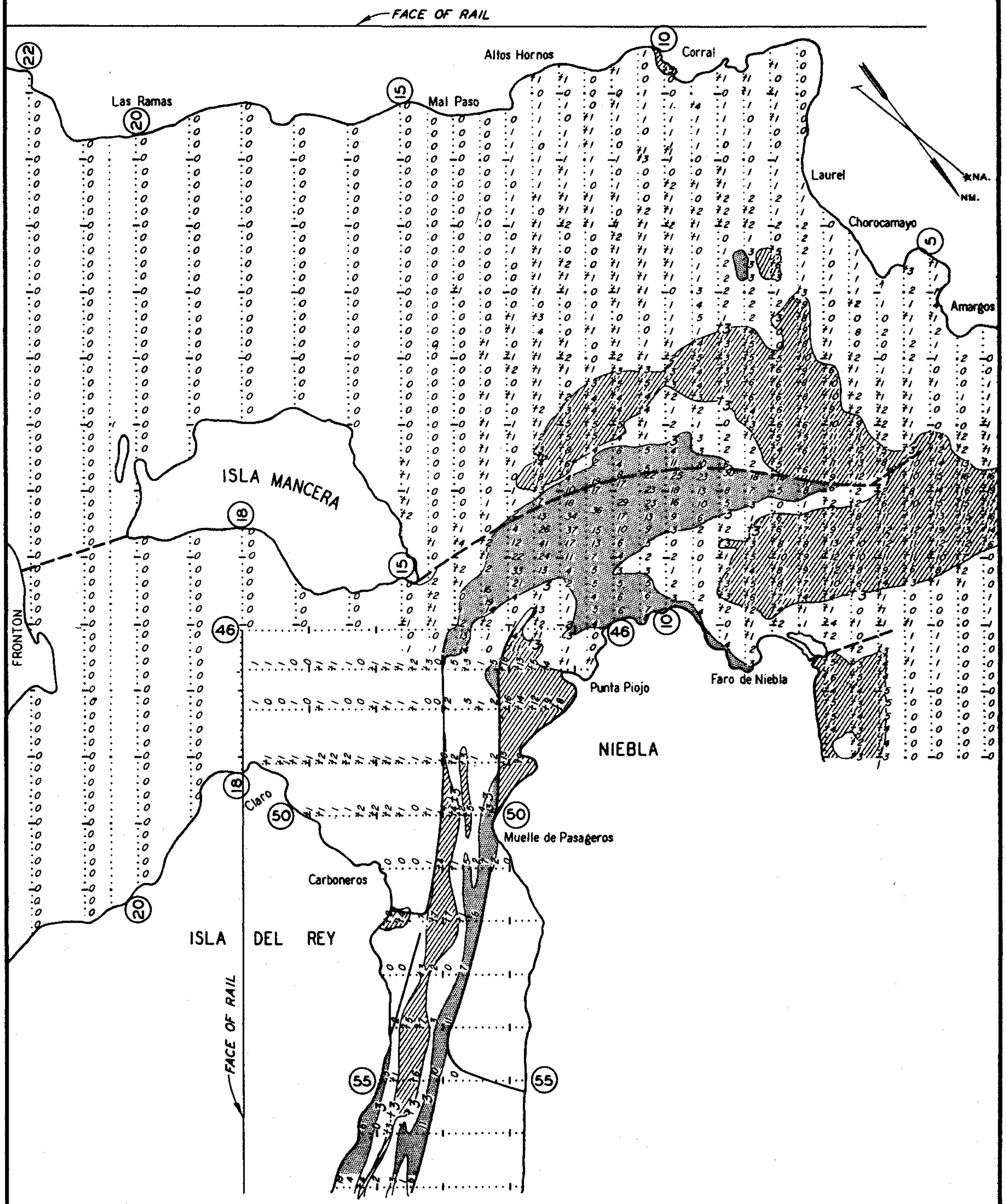
PROTOTYPE 1000 0 1000 2000 FT

MODEL 1 0 1 2 3 4 5 FT

LEGEND

- EXISTING STRUCTURE
- PROPOSED STRUCTURE
- MORE THAN 6 METERS DEEP MLLW
- LESS THAN 6 METERS DEEP MLLW
- (15) SOUNDING RANGE

NOTE: SOUNDINGS ARE IN FEET BELOW MEAN LOWER LOW WATER (MLLW). CONTOURS ARE IN METERS BELOW MLLW.



LEGEND

- EXISTING STRUCTURE
- PROPOSED STRUCTURE
- MORE THAN 3 FEET OF FILL
- LESS THAN 3 FEET OF SCOUR OR FILL
- MORE THAN 3 FEET OF SCOUR
- (15) SOUNDING RANGE

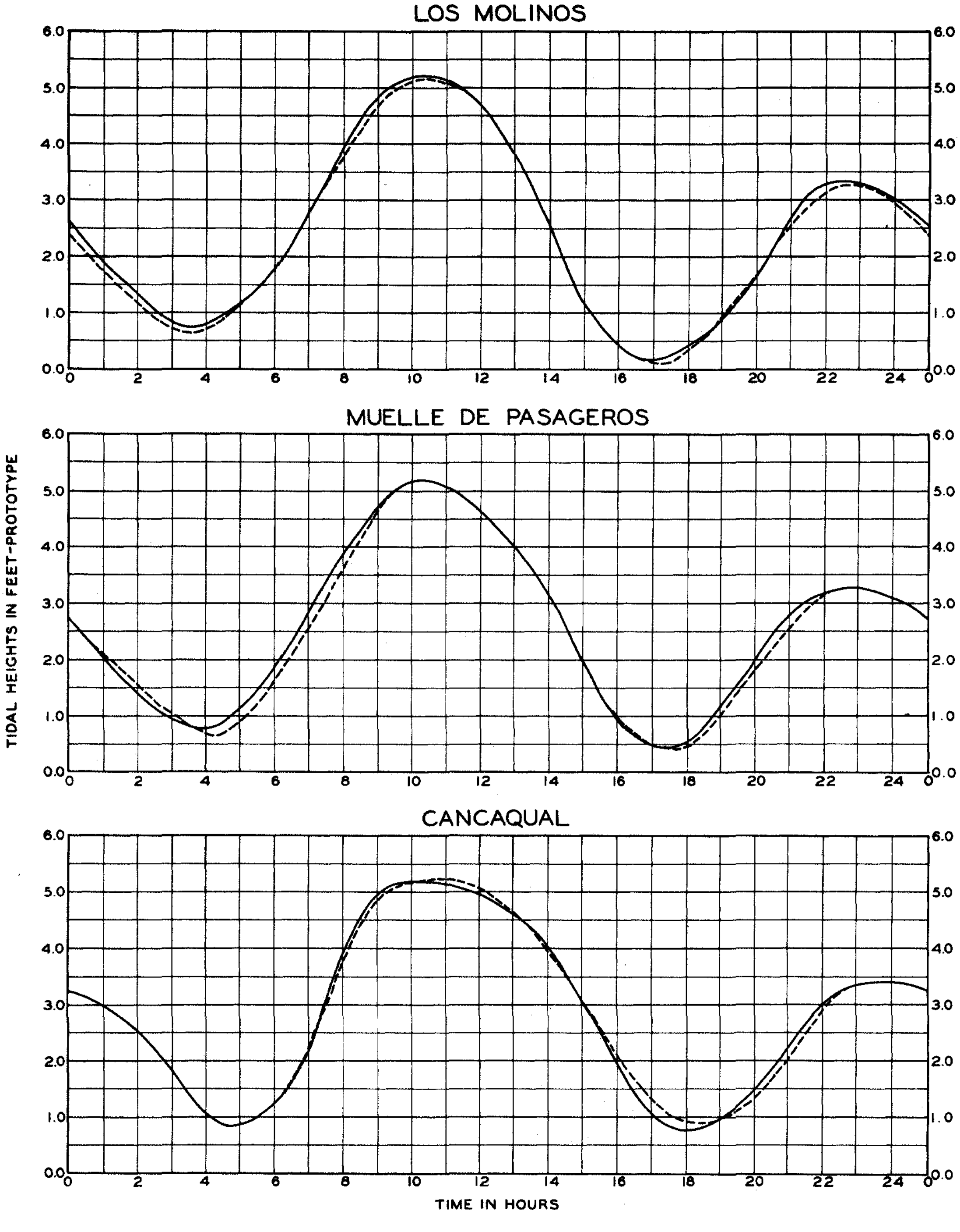
NOTE: VALUES SHOWN REPRESENT THE TOTAL CHANGE IN FEET FROM START TO END OF TEST.

PLAN 5
SCOUR AND FILL DURING TEST

SCALES

PROTOTYPE 1000 0 1000 2000 FT

MODEL 1 0 1 2 3 4 5 FT



LEGEND

——— BASE TEST TIDAL HEIGHTS

------ PLAN TIDAL HEIGHTS

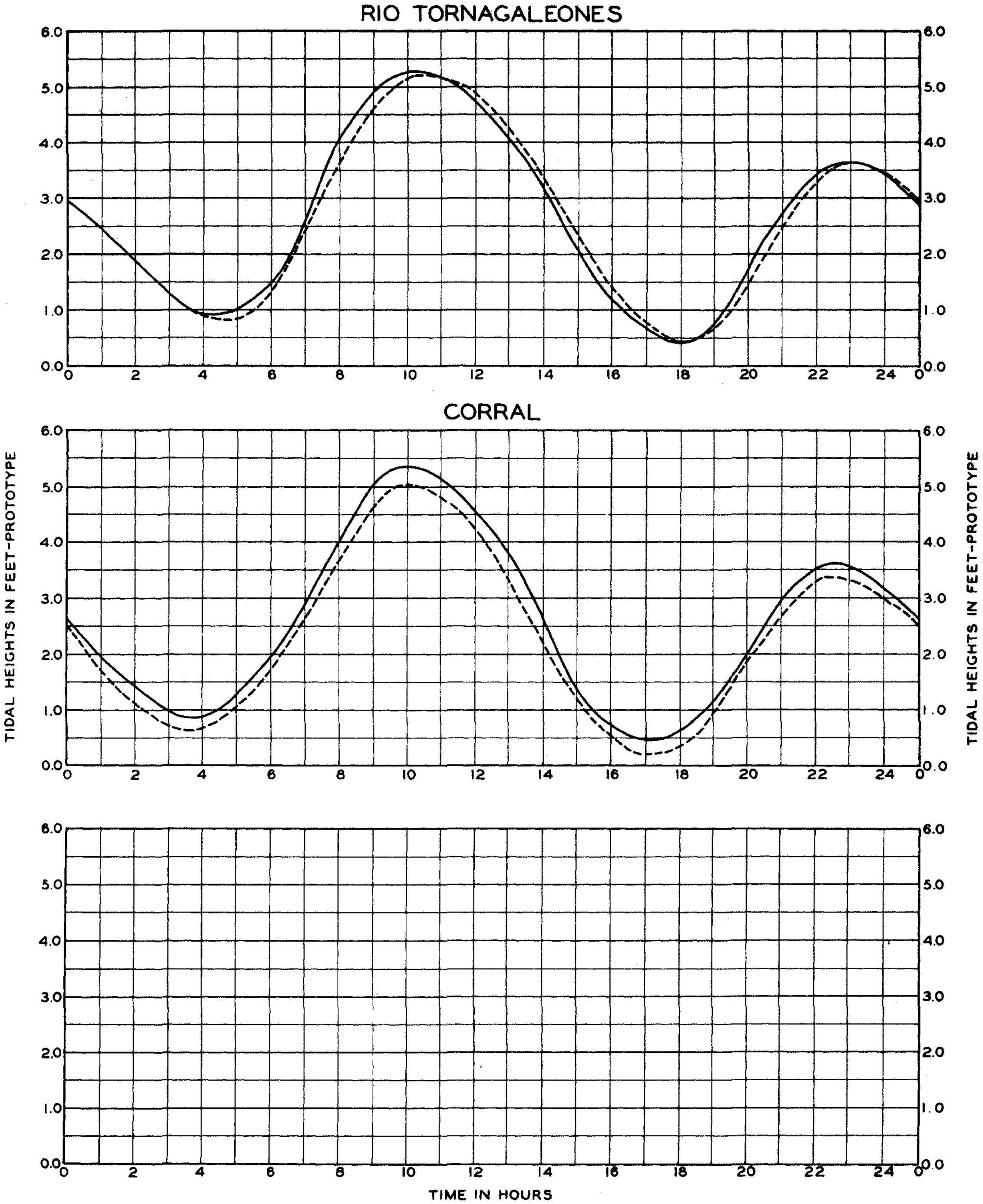
NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF CORRAL MERIDIAN.

TIDAL HEIGHTS REFERRED TO MEAN LOWER LOW WATER AT LOS MOLINOS.

TIDE CURVES

PLAN 5

LOS MOLINOS, MUELLE DE PASAGEROS AND CANCAQUAL



LEGEND

——— BASE TEST TIDAL HEIGHTS

- - - - - PLAN TIDAL HEIGHTS

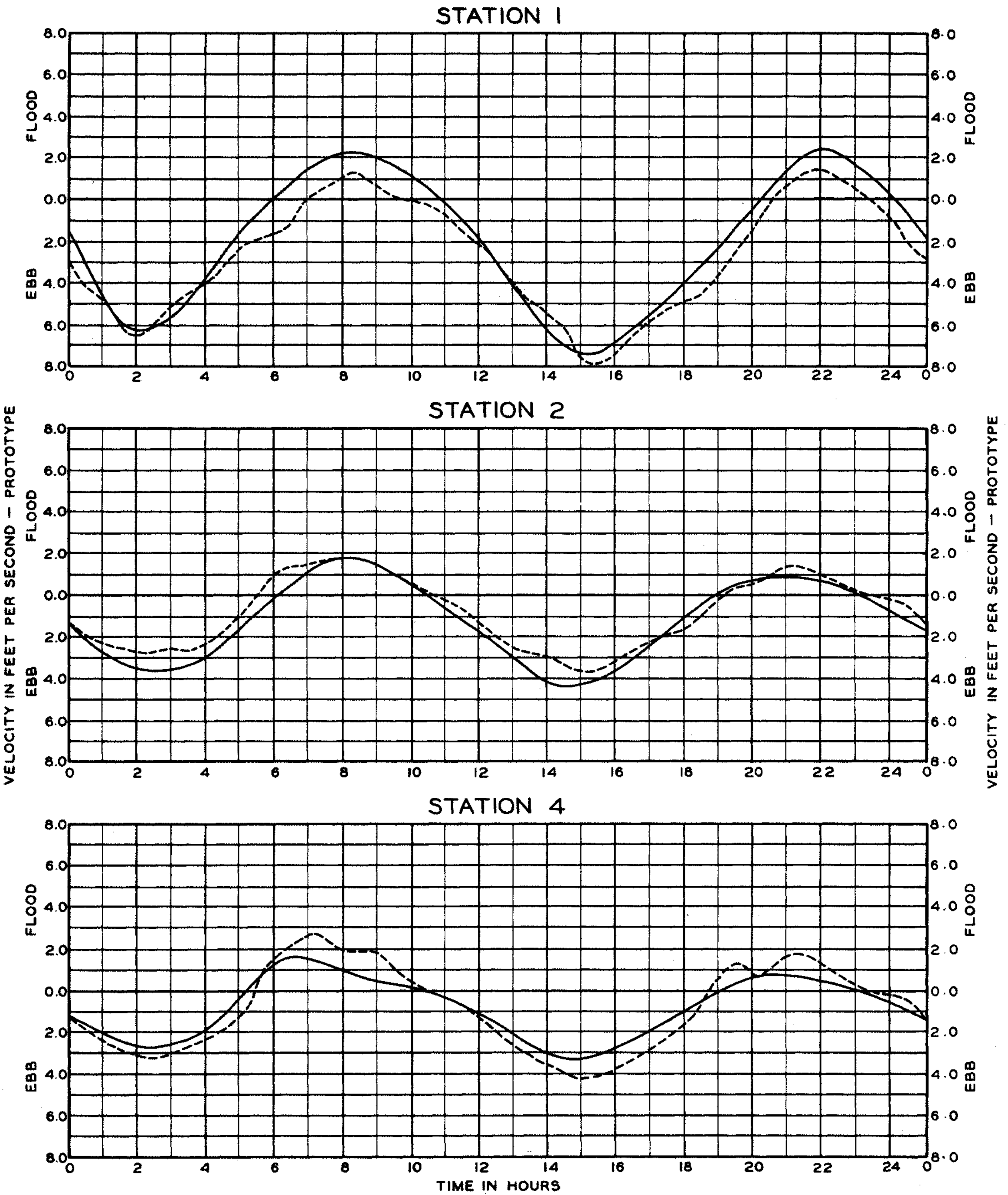
NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF CORRAL MERIDIAN.

TIDAL HEIGHTS REFERRED TO MEAN LOWER LOW WATER AT LOS MOLINOS.

TIDE CURVES

PLAN 5

RIO TORNAGALEONES AND CORRAL



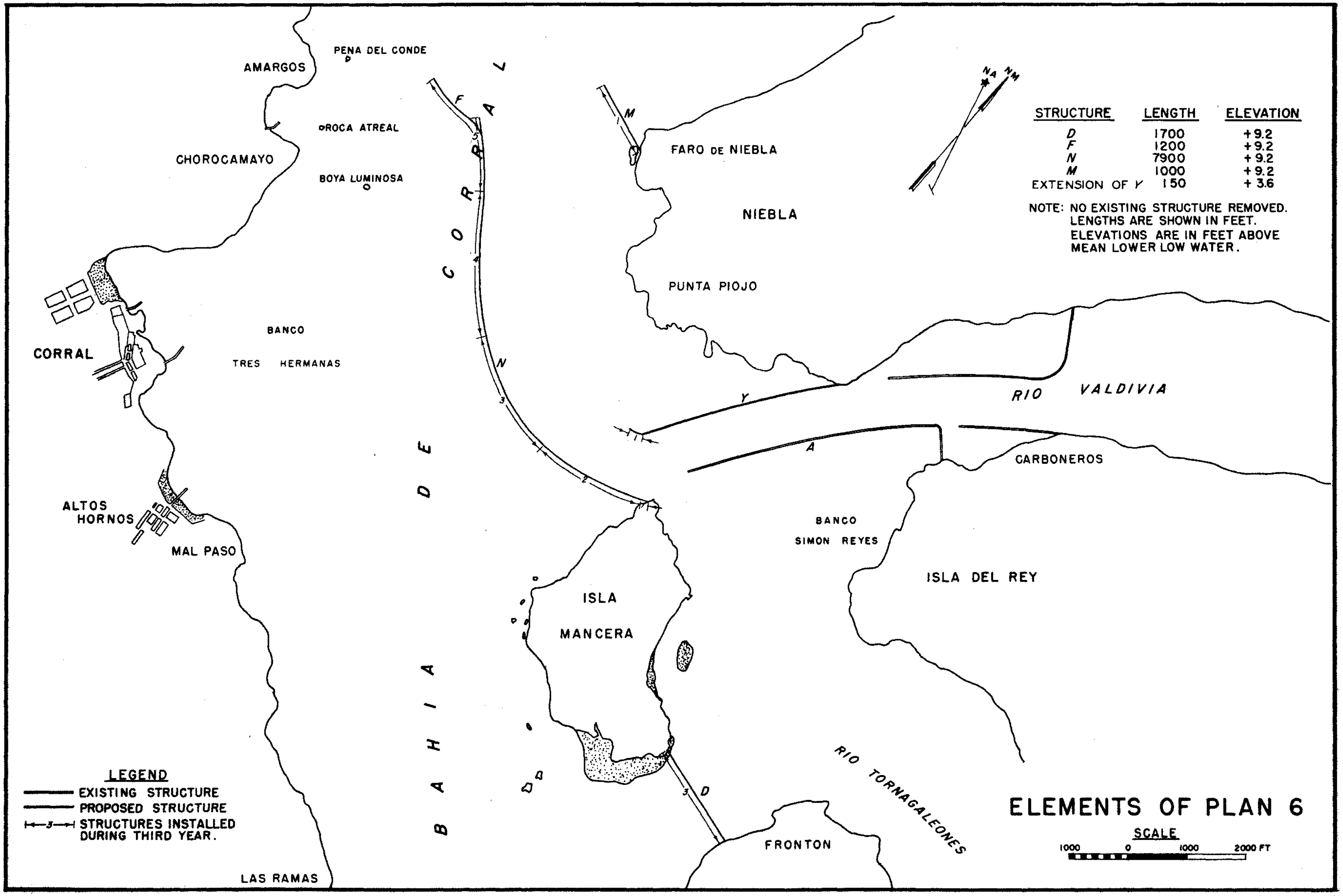
LEGEND

——— BASE TEST VELOCITY CURVES

- - - - PLAN VELOCITY CURVES

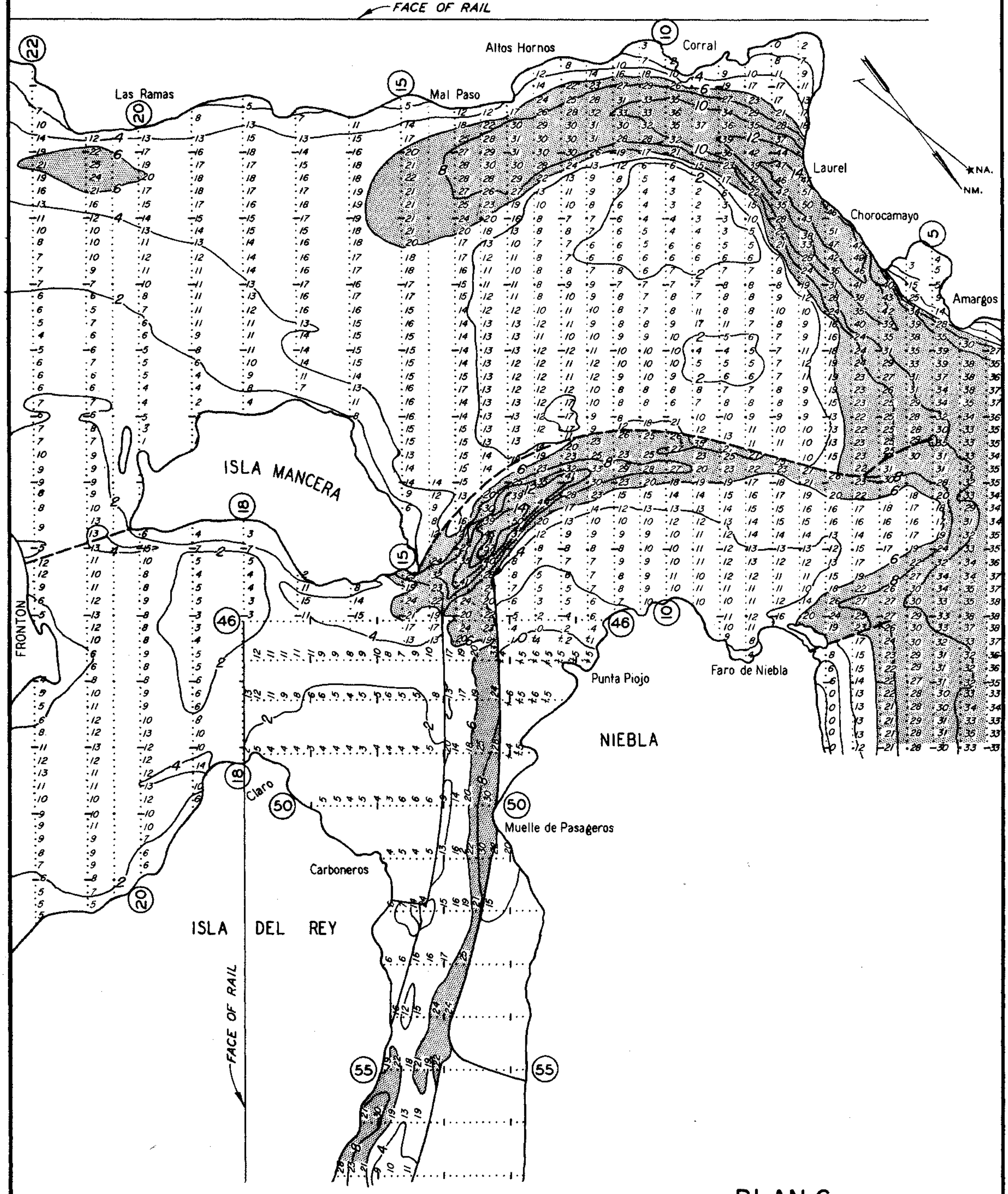
NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF CORRAL MERIDIAN.

VELOCITY CURVES
PLAN 5



ELEMENTS OF PLAN 6

PLATE 45



PLAN 6
CONDITION OF MOVABLE BED AT END OF TEST
DURATION OF TEST 12 YEARS

LEGEND

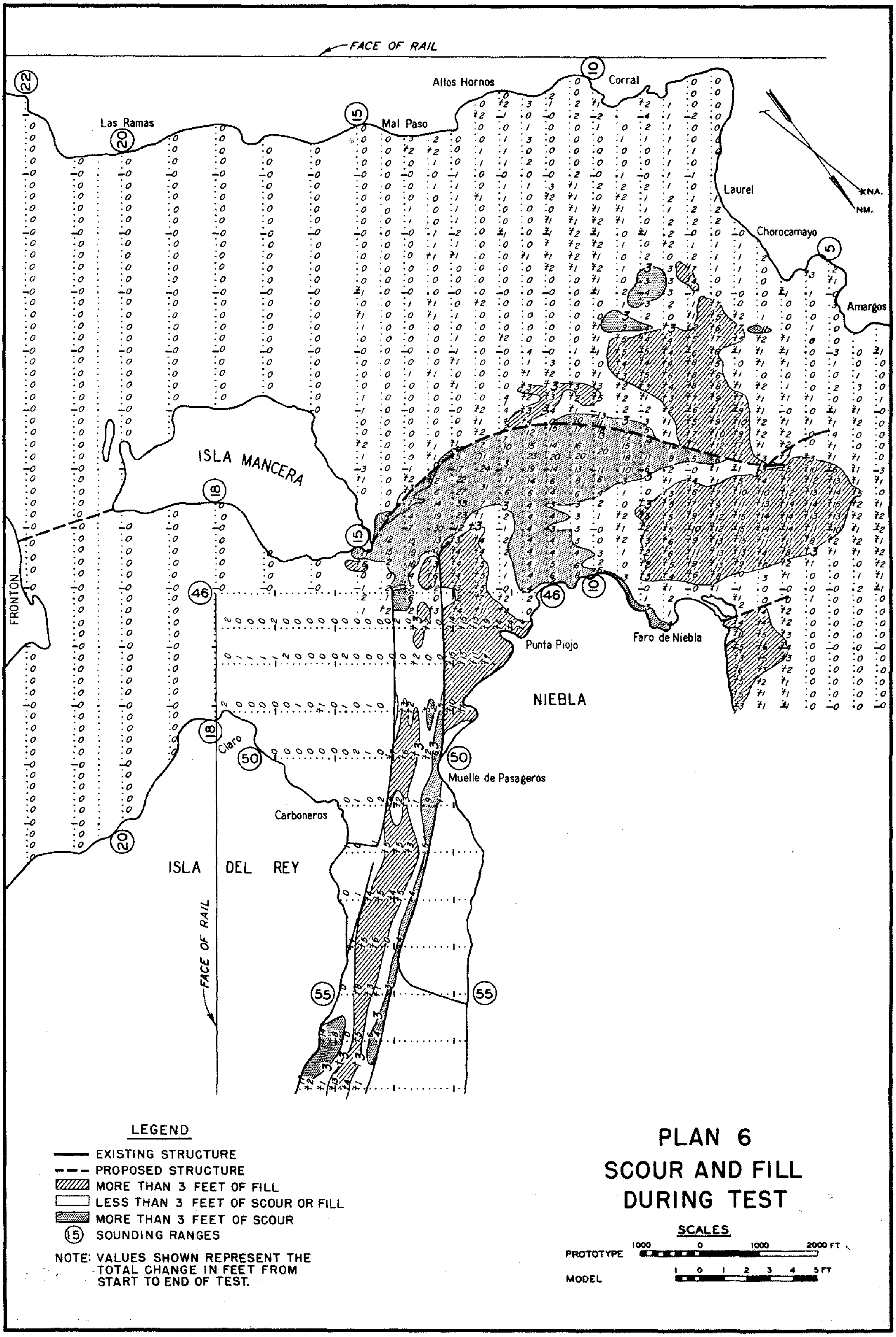
- EXISTING STRUCTURE
- PROPOSED STRUCTURE
- MORE THAN 6 METERS DEEP MLLW
- LESS THAN 6 METERS DEEP MLLW
- (15) SOUNDING RANGE

NOTE: SOUNDINGS ARE IN FEET BELOW MEAN LOWER LOW WATER (MLLW). CONTOURS ARE IN METERS BELOW MLLW.

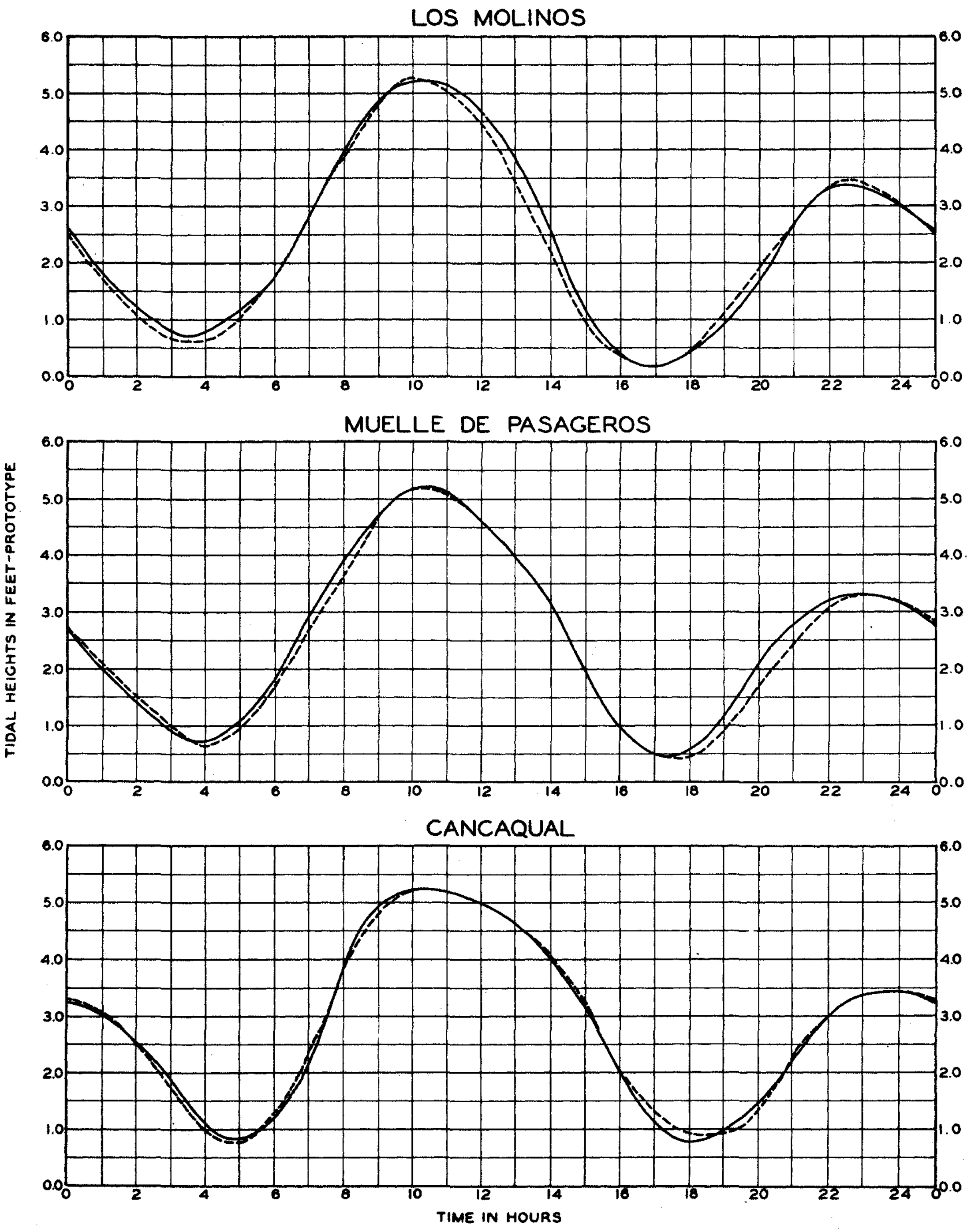
SCALES

PROTOTYPE 1000 0 1000 2000 FT

MODEL 1 0 1 2 3 4 5 FT



PLAN 6
SCOUR AND FILL
DURING TEST



LEGEND

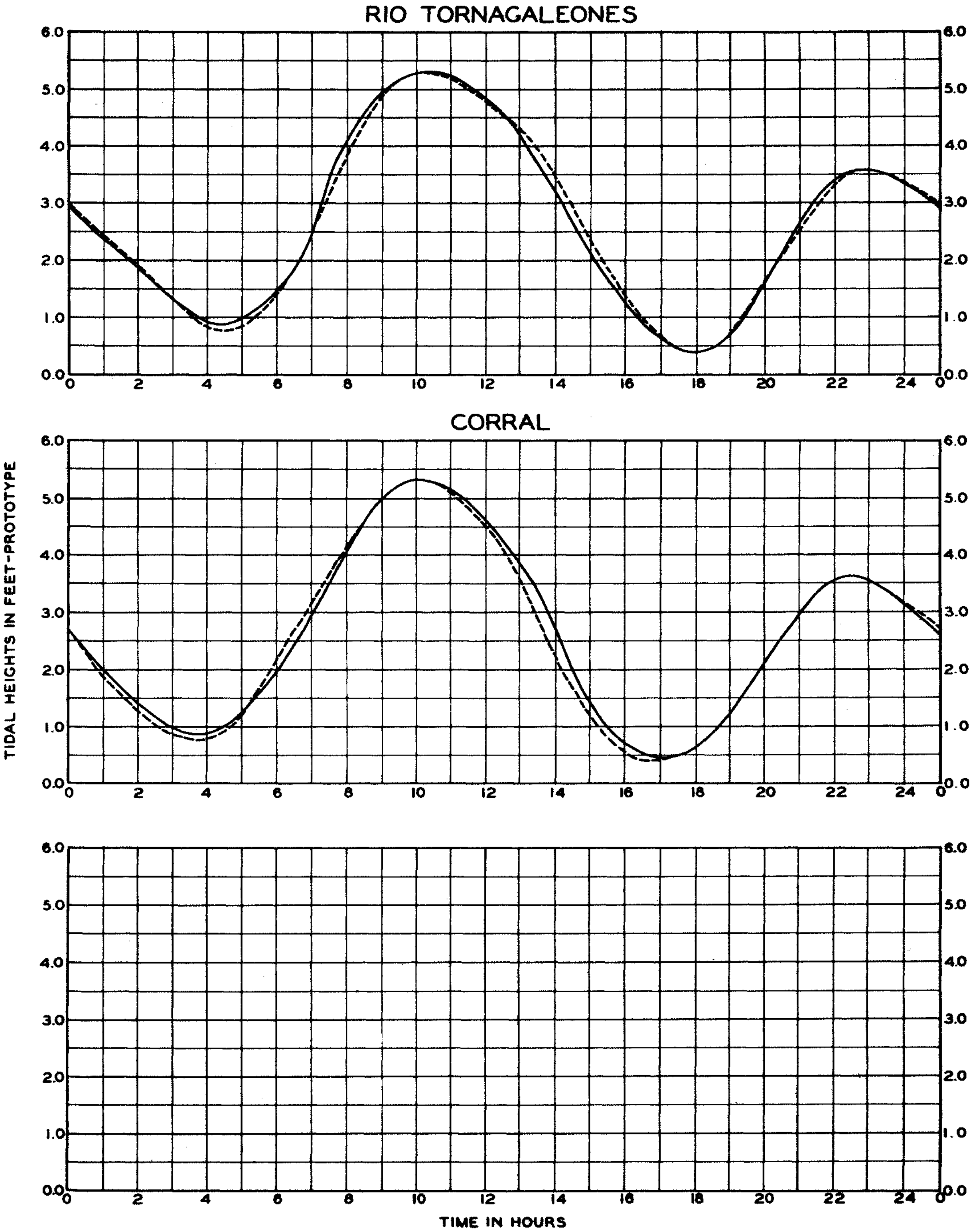
——— BASE TEST TIDAL HEIGHTS

------- PLAN TIDAL HEIGHTS

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF CORRAL MERIDIAN.

TIDAL HEIGHTS REFERRED TO MEAN LOWER LOW WATER AT LOS MOLINOS.

TIDE CURVES
PLAN 6
LOS MOLINOS, MUELLE DE PASAGEROS
AND CANCAQUAL



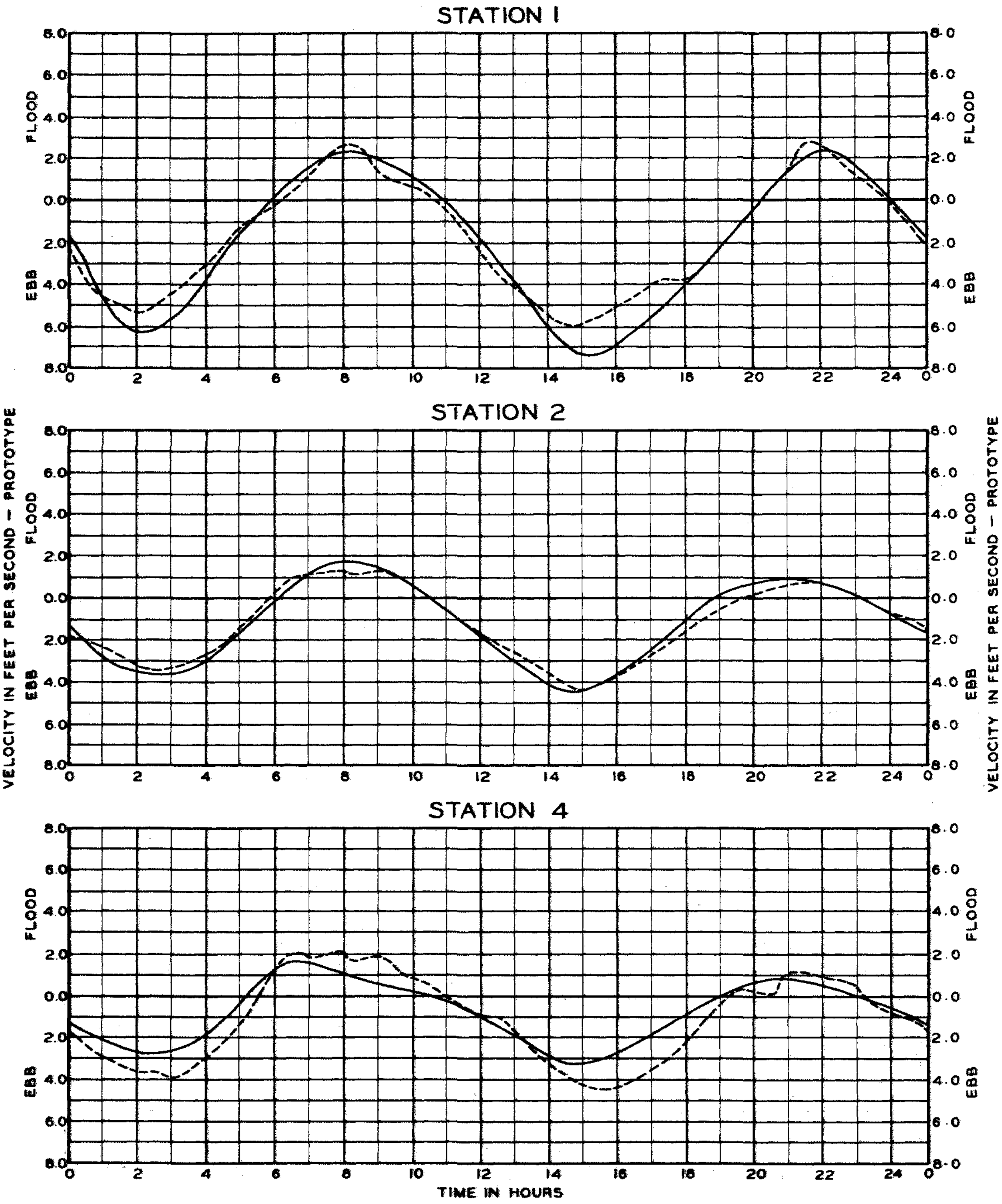
LEGEND

——— BASE TEST TIDAL HEIGHTS
- - - - - PLAN TIDAL HEIGHTS

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF CORRAL MERIDIAN.

TIDAL HEIGHTS REFERRED TO MEAN LOWER LOW WATER AT LOS MOLINOS.

TIDE CURVES
PLAN 6
RIO TORNAGALEONES AND CORRAL



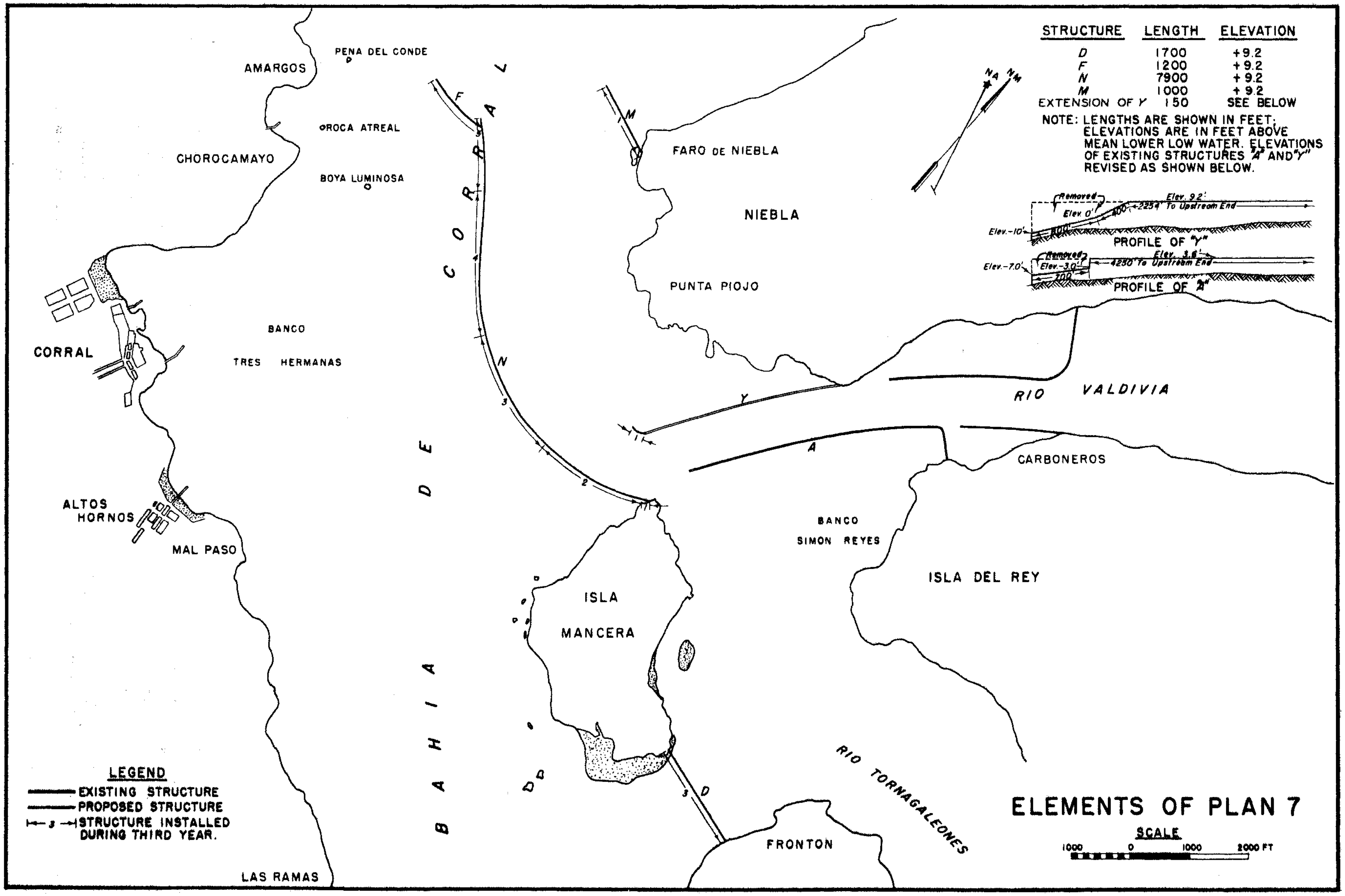
LEGEND

——— BASE TEST VELOCITY CURVES

- - - - PLAN VELOCITY CURVES

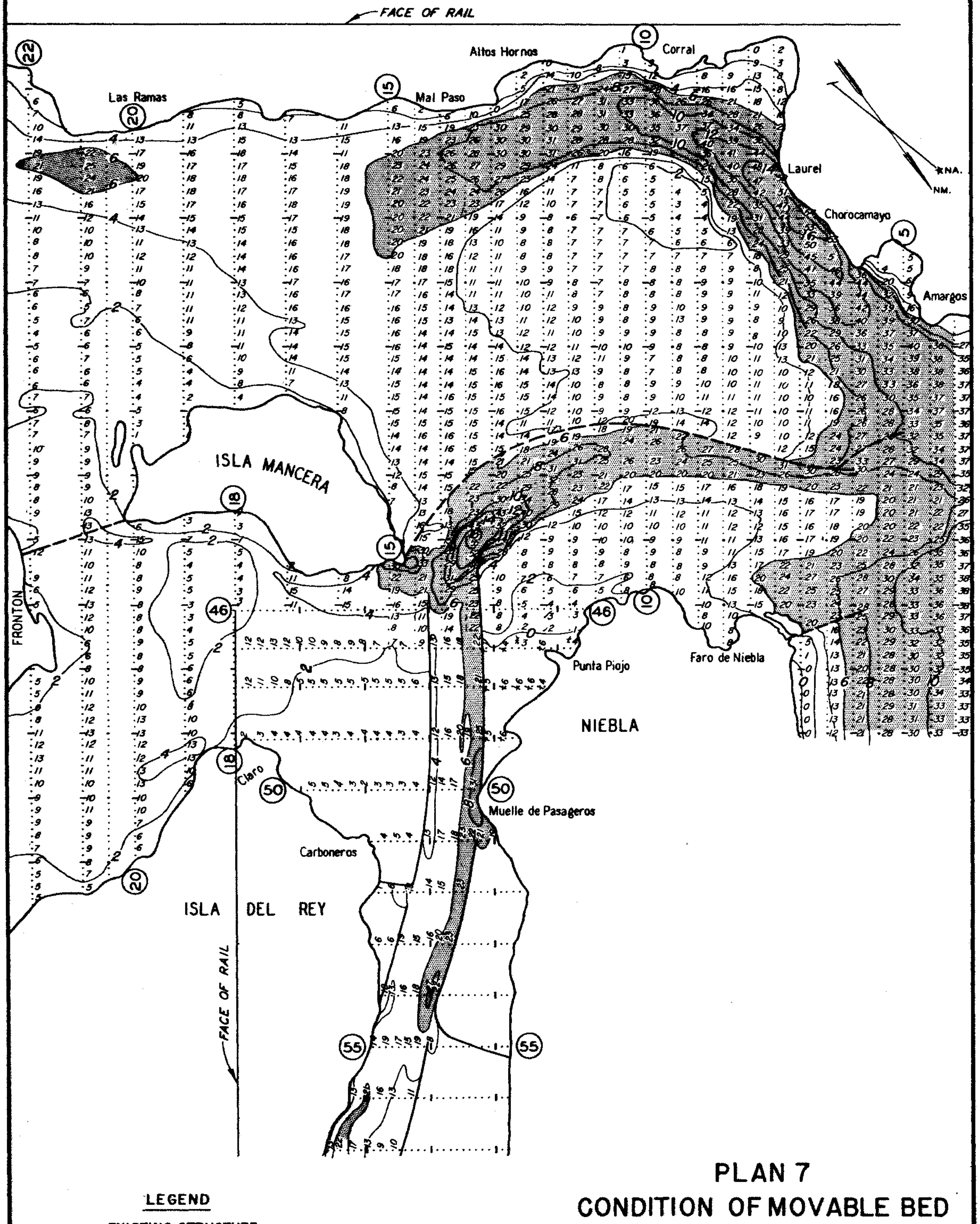
NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF CORRAL MERIDIAN.

VELOCITY CURVES
PLAN 6



STRUCTURE LENGTH ELEVATION
D 1700 +9.2
F 1200 +9.2
N 7900 +9.2
M 1000 +9.2
EXTENSION OF Y 150 SEE BELOW
NOTE: LENGTHS ARE SHOWN IN FEET; ELEVATIONS ARE IN FEET ABOVE MEAN LOWER LOW WATER. ELEVATIONS OF EXISTING STRUCTURES "A" AND "Y" REVISED AS SHOWN BELOW.
Removed
Elev. 9.2'
Elev. 0'
2254' To Upstream End
Elev. -10'
PROFILE OF "Y"
Removed
Elev. 3.6'
Elev. -7.0'
Elev. -3.0'
4250' To Upstream End
700
PROFILE OF "A"
NA
NM
PENA DEL CONDE
AMARGOS
ROCA ATREAL
CHOROCAMAYO
BOYA LUMINOSA
FARO DE NIEBLA
NIEBLA
PUNTA PIOJO
BANCO
TRES HERMANAS
CORRAL
BAHIA DE CORRAL
RIO VALDIVIA
CARBONEROS
ALTOS HORNOS
MAL PASO
BANCO
SIMON REYES
ISLA DEL REY
ISLA MANCERA
RIO TORNAGALEONES
FRONTON
LAS RAMAS
LEGEND
EXISTING STRUCTURE
PROPOSED STRUCTURE
STRUCTURE INSTALLED DURING THIRD YEAR.
ELEMENTS OF PLAN 7
SCALE
1000 0 1000 2000 FT

PLATE 51



LEGEND

- EXISTING STRUCTURE
- PROPOSED STRUCTURE
- MORE THAN 6 METERS DEEP MLLW
- LESS THAN 6 METERS DEEP MLLW
- (15) SOUNDING RANGE

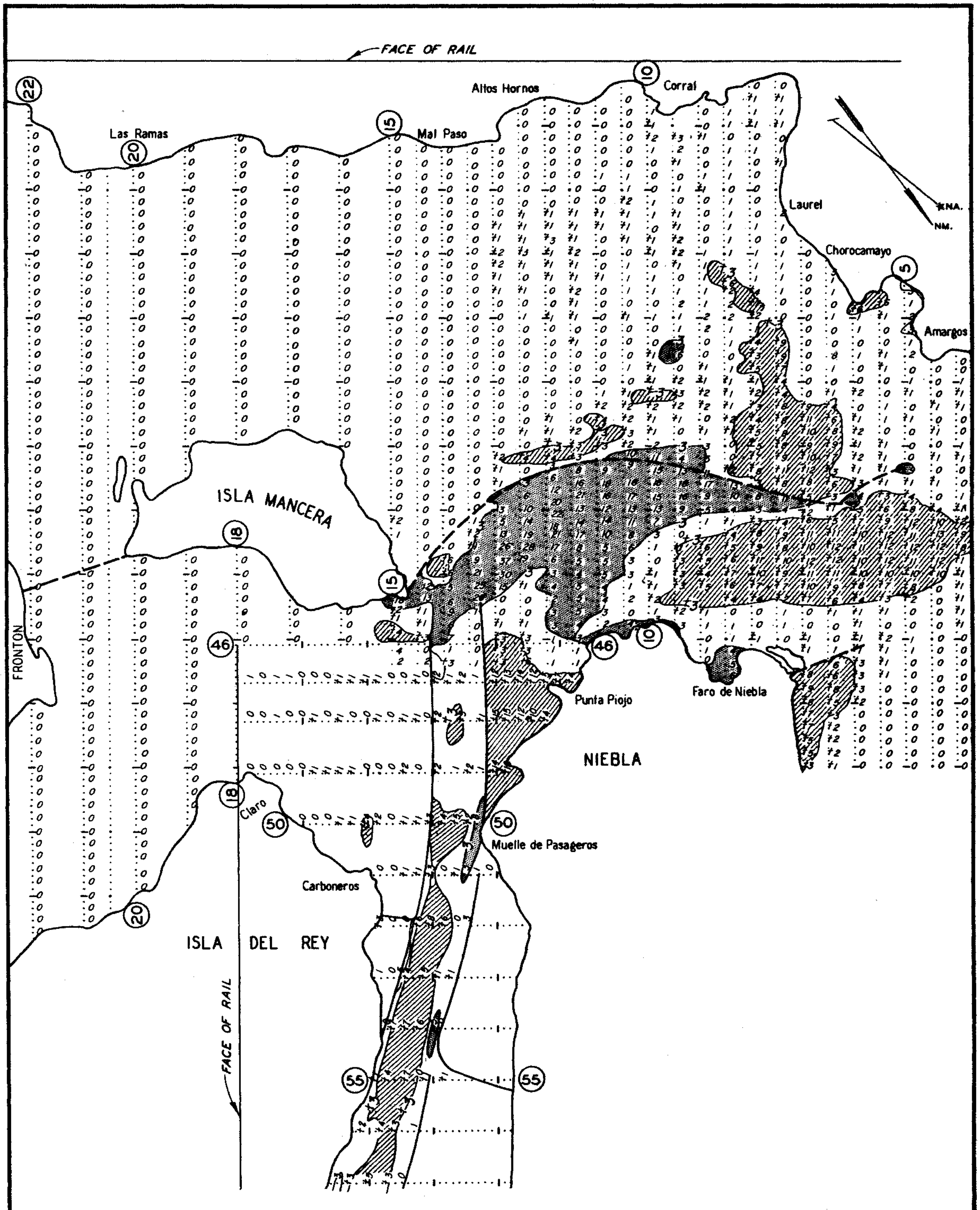
NOTE: SOUNDINGS ARE IN FEET BELOW MEAN LOWER LOW WATER (MLLW). CONTOURS ARE IN METERS BELOW MLLW.

PLAN 7
CONDITION OF MOVABLE BED AT END OF TEST
DURATION OF TEST 12 YEARS

SCALES

PROTOTYPE 1000 0 1000 2000 FT

MODEL 1 0 1 2 3 4 5 FT



LEGEND

- EXISTING STRUCTURE
- PROPOSED STRUCTURE
- MORE THAN 3 FEET OF FILL
- LESS THAN 3 FEET OF SCOUR OR FILL
- MORE THAN 3 FEET OF SCOUR
- (15) SOUNDING RANGES

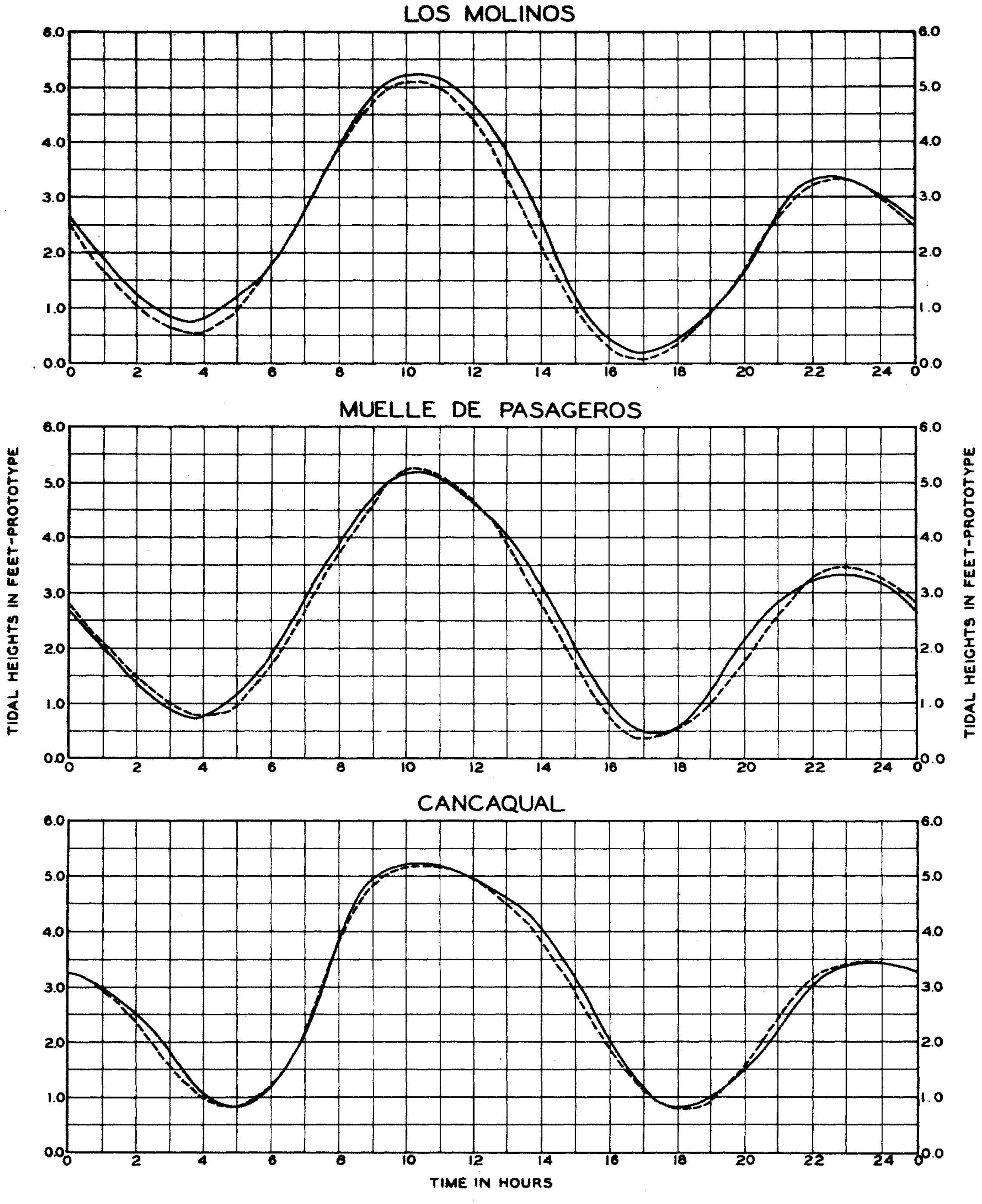
NOTE: VALUES SHOWN REPRESENT THE TOTAL CHANGE IN FEET FROM START TO END OF TEST!

PLAN 7
SCOUR AND FILL DURING TEST

SCALES

PROTOTYPE 1000 0 1000 2000 FT

MODEL 1 0 1 2 3 4 5 FT



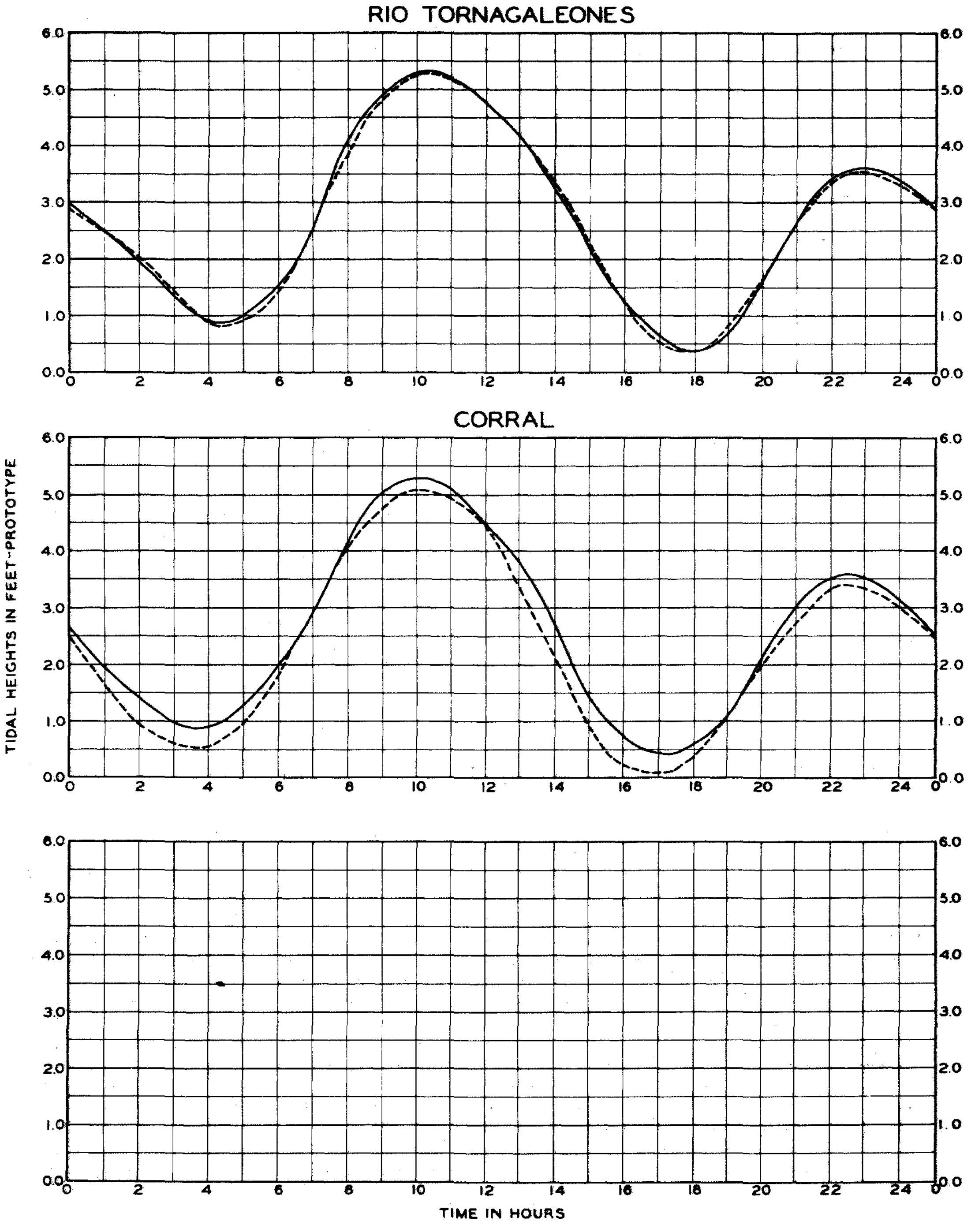
LEGEND

——— BASE TEST TIDAL HEIGHTS
- - - - - PLAN TIDAL HEIGHTS

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF CORRAL MERIDIAN.

TIDAL HEIGHTS REFERRED TO MEAN LOWER LOW WATER AT LOS MOLINOS.

TIDE CURVES
PLAN 7
LOS MOLINOS, MUELLE DE PASAGEROS
AND CANCAQUAL



LEGEND

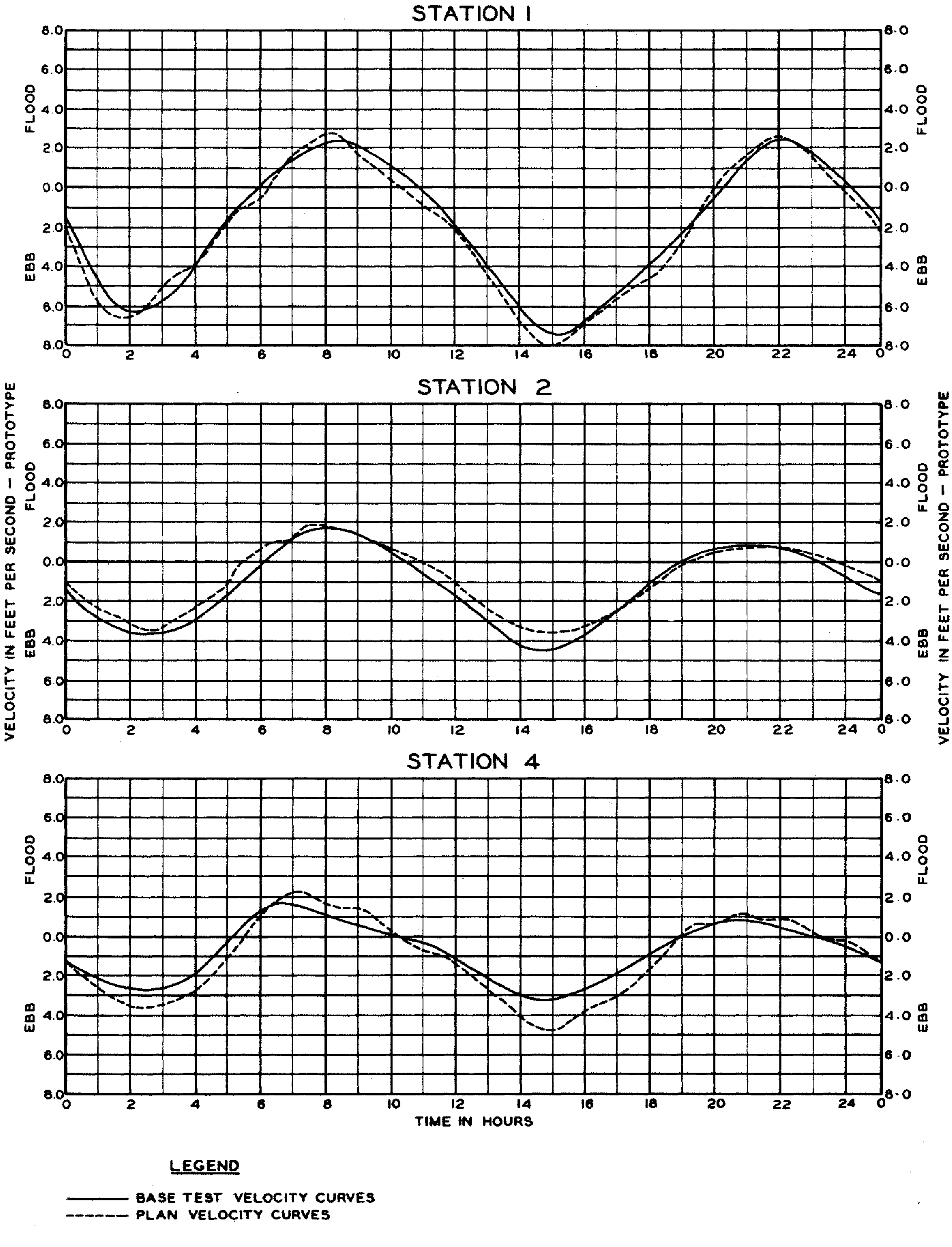
——— BASE TEST TIDAL HEIGHTS

- - - - - PLAN TIDAL HEIGHTS

NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF CORRAL MERIDIAN.

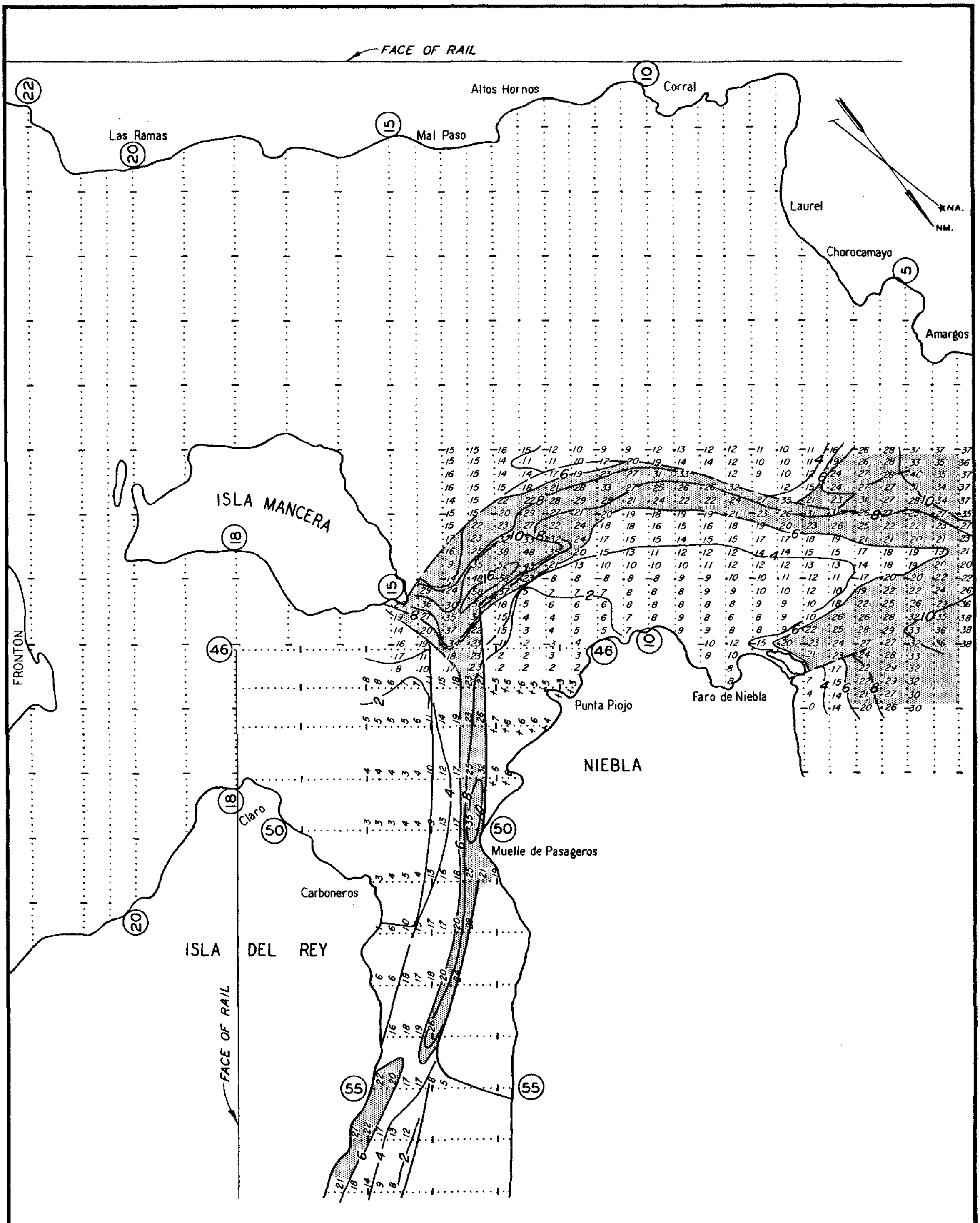
TIDAL HEIGHTS REFERRED TO MEAN LOWER LOW WATER AT LOS MOLINOS.

TIDE CURVES
PLAN 7
RIO TORNAGALEONES AND CORRAL



NOTE: TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF CORRAL MERIDIAN.

VELOCITY CURVES
PLAN 7



LEGEND

—— EXISTING STRUCTURE
– – – PROPOSED STRUCTURE
MORE THAN 6 METERS DEEP MLLW
LESS THAN 6 METERS DEEP MLLW
(15) SOUNDING RANGE

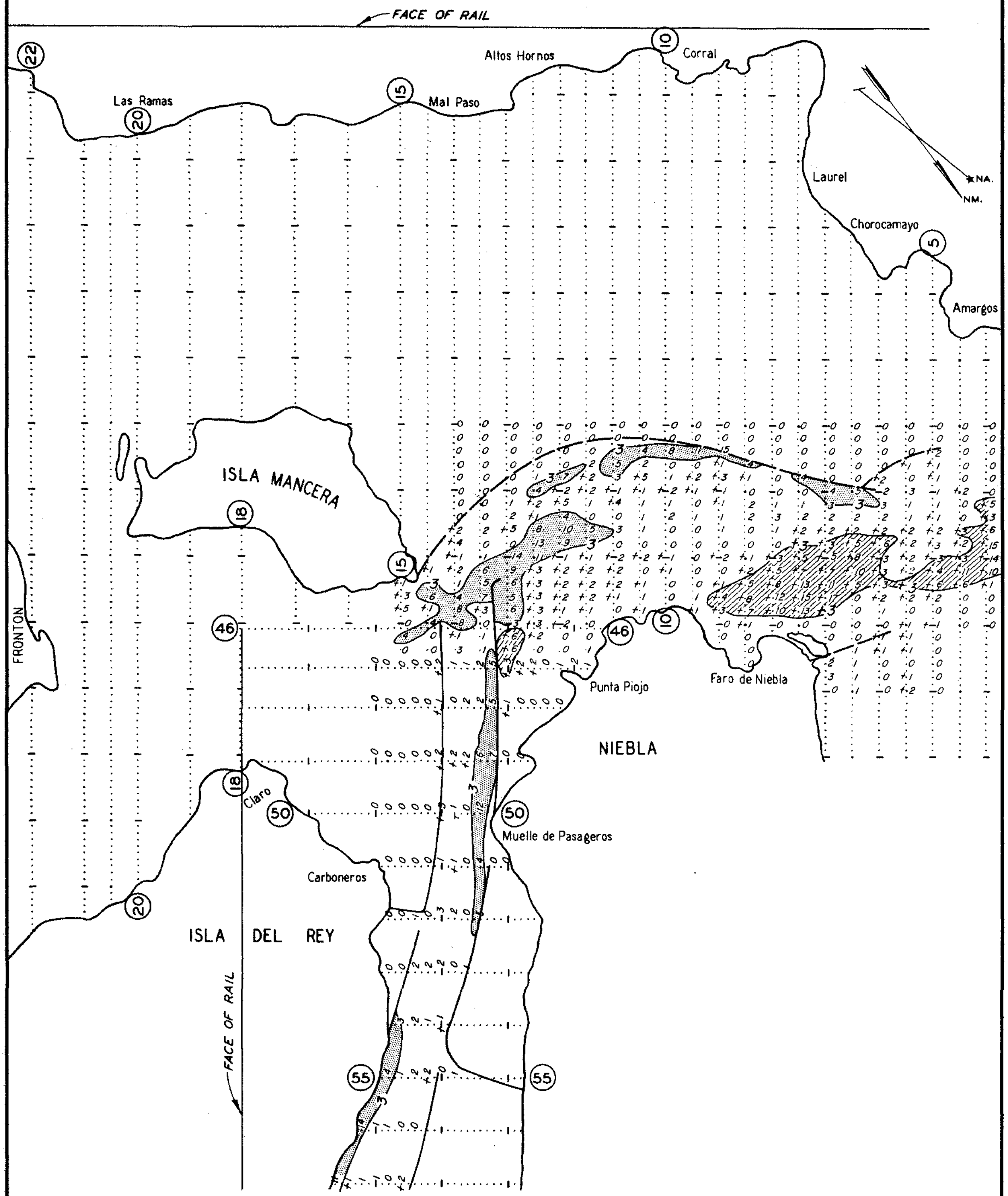
NOTE: SOUNDINGS ARE IN FEET BELOW MEAN LOWER LOW WATER (MLLW). CONTOURS ARE IN METERS BELOW MLLW.

PLAN 7
CONDITION OF MOVABLE BED AT END OF EXTENDED TEST

SCALES

PROTOTYPE 1000 0 1000 2000 FT

MODEL 1 0 1 2 3 4 5 FT



LEGEND

- EXISTING STRUCTURE
- PROPOSED STRUCTURE
- MORE THAN 3 FEET OF FILL
- LESS THAN 3 FEET OF SCOUR OR FILL
- MORE THAN 3 FEET OF SCOUR
- (15) SOUNDING RANGE

NOTE: VALUES SHOWN REPRESENT THE TOTAL CHANGE IN FEET FROM THE END OF 12 YEARS OPERATION TO THE END OF 14 YEARS OPERATION.

PLAN 7
SCOUR AND FILL DURING EXTENDED TEST

SCALES

PROTOTYPE 1000 0 1000 2000 FT

MODEL 1 0 1 2 3 4 5 FT